TABLE 2.

Analyses of Aluminous Pelites.

	1	2	3	4	5	6	7	8
SiO_2	56·28	54·01	49·53	54·18	55·49	56·33	60·15	53·29
Al_2O_3	23·02	24·41	26·53	25·48	24·45	22·94	16·45	22·38
Fe_2O_3	1·82	1·39	2·17	2·99	2·21	2·19	4·04	} 6·57
FeO	5·84	5·95	6·01	3·08	4·92	4·54	2·90	
MgO	3·28	2·91	3·15	3·13	2·88	3·27	2·32	2·10
CaO	0·14	0·36	0·37	0·41	0·35	0·25	1·41	0·53
Na_2O	1·21	1·09	1·23	0·73	0·54	0·88	1·01	1·11
K_2O	4·97	5·45	5·90	5·70	5·21	6·10	3·60	7·43
H_2O+	2·82	2·64	3·79	2·88	2·09	3·07	3·82	} 4·12
H_2O-	0·24	0·28	0·31	0·48	0·07	0·80	0·89	
TiO_2	0·77	0·85	1·03	0·73	0·78	—	0·76	0·91
P_2O_5	0·10	0·15	—	0·07	0·20	0·13	0·15	—
MnO	0·06	0·07	0·06	0·03	0·09	tr.	tr.	—
CO_2..	—	—	—	—	0·30	—	1·46	0·58
C	—	—	—	0·34	0·03	—	0·88	—
Etc.	—	—	—	—	—	—	0·62	—
	100·55	99·56	100·08	100·23	99·61	100·50	100·46	99·02

1. Knotted schist. Por. 65, Par. of Yabtree, Co. Wynyard. Anal. T. G. Vallance.
2. Spotted granulite. Mt. Pleasant Creek, Por. 32, Par. of Wallace, Co. Wynyard. Anal. T. G. Vallance.
3. Spotted granulite. East end of Yaven Creek bridge, Por. 51, Par. of Dutzon, Co. Wynyard. Anal. T. G. Vallance.
4. Chlorite-sericite-schist. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 164.
5. Knotted schist. Albury area. Anal. G. A. Joplin. *Ibid.*, 72, 1947: 88.
6. Phyllite. Ensay area. Anal. A. W. Howitt. *Proc. Roy. Soc. Vict.*, 22, 1886: 68.
7. Average of fifty-one Paleozoic shales (H. N. Stokes). From *U.S. Geol. Surv. Bull.* 616, 1916: 546.
8. Slightly altered shale. Phillipsburg area (Montana). Anal. W. T. Schaller. *U.S. Geol. Surv. Prof. Paper no.* 78, 1913: 57.

for the potash in the present case. It seems reasonable to relate the richness in potash to an original richness in micaceous constituents.

Pelites with less than the usual amount of magnesia have been found in this area, as at Albury and in Victoria. In Table 3 some examples of such rocks are given. The rock no. 2 of this table has high alkali values, due mainly to the presence of an abnormal amount of finely-divided sodic felspar. Lime, too, is rather higher than normal here. The dominance of potash over soda is, however, clear in these examples just as in the "normal" pelites.

In the low-grade zone, in particular, there is a certain development of grey-green to buff coloured slaty rocks which, when analysed, are found to contain much more silica than is usual for apparently comparable rocks of this area. Some of these slates consist of an admixture of fine silty material (mainly quartz) and clay (now represented by mica) and are not unlike the psammopelites in mineralogy and chemical composition. They seem to be merely finer-grained equivalents of the subgreywackes and, if unmetamorphosed, would have probably fallen into the category of "subgreywacke shales" (Dapples, Krumbein and Sloss, 1950). Text-figure 3 is an uncorrected ACF diagram depicting the fields of the so-called "normal" pelites and "siliceous" pelites (from Joplin, 1945). On this have been plotted several analyses of the siliceous rocks in question as well as some psammopelites from this area and from Cooma. There is an apparent gradation (textural as well as chemical) between the various types. An analysis of a fine-grained psammopelite (it is nearly fine enough to be called a pelite) is given in Table 1 (no. 4). The composition of the grey-green slates is probably not greatly different from this. Texturally these rocks are pelites but chemically they approach psammopelites; they will be referred to here as siliceous pelites.

Black well-cleaved siliceous slates, important at Cooma but absent at Albury, are not very abundant in this area. These rocks may have a different origin from that of the grey-green or buff coloured slates mentioned above. The black, sometimes graptolite-bearing, slates may be derived from volcanic ash (Joplin, 1945). It seems not improbable that there are two distinct sedimentary types (the silty "subgreywacke shales" and the carbonaceous black slates) included under the name "siliceous pelite" in the literature on the rocks of this metamorphic belt and from Cooma.

TABLE 3.

Pelites Poor in Magnesia.

	1	2	3	4
SiO_2	52·55	57·55	53·88	52·91
Al_2O_3	23·55	21·36	27·95	24·49
Fe_2O_3	5·01	2·60	5·04	5·45
FeO	4·52	1·76	0·69	1·50
MgO	1·90	0·98	1·02	1·80
CaO	0·37	1·34	0·19	0·29
Na_2O	0·27	3·16	0·34	1·08
K_2O	6·64	7·99	5·64	6·60
H_2O+	3·48	2·30	3·44	3·81
H_2O-	0·55	0·17	0·72	0·61
TiO_2	0·75	0·81	1·12	0·83
P_2O_5	0·11	—	0·07	0·10
MnO	0·02	0·06	0·03	0·06
BaO	—	—	—	0·06
C	—	—	0·53	0·19
	99·72	100·08	100·66	99·78

1. Phyllite. Near Humula Trig. Stn., Por. 224, Par. of Umbango, Co. Wynyard. Anal. T. G. Vallance.
2. Phyllite. Por. 194, Par. of Ellerslie, Co. Wynyard. Anal. T. G. Vallance.
3. Dark grey slate. Jingellic area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 72, 1947: 89.
4. Slate. Tallangatta area. Anal. C. M. Tattam. *Geol. Surv. Vict., Bull.* 52, 1929: 35.

GEOSYNCLINAL ENVIRONMENT.

The lithological assemblage just described appears to be fairly typical of what one would expect of sedimentation under miogeosynclinal conditions. The essential rock types are alternating shales (slates) and subgreywackes with only local signs of contemporaneous igneous activity and one very restricted patch of limestone. Jaspers, which occur in the Nangus area, are probably not original sediments.

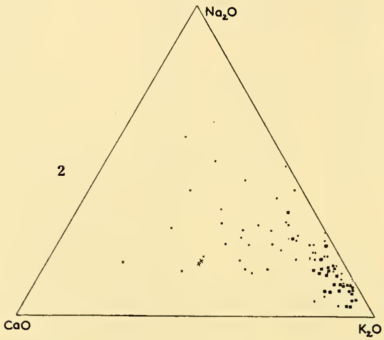
The association shale(slate)-subgreywacke with no conglomerates and not much orthoquartzitic material suggests that the sediments were deposited towards the axial parts of the miogeosyncline. Sedimentary facies indicative of the marginal and shelf environments have not been recognized. They may be buried beneath later deposits further to the west.

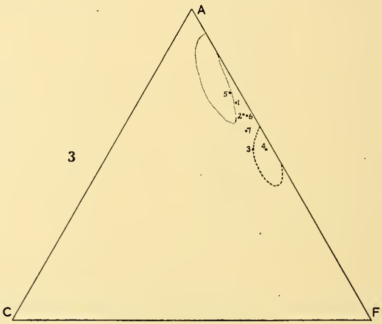
It may be noted that the Phillipsburg area referred to above (Emmons and Calkins, 1913) is also characterized by miogeosynclinal sediments (see Kay, 1951) in which plutonic masses have been emplaced. The metamorphic changes induced in the Phillipsburg pelites are somewhat similar to those to be described here. Such cases are of interest in view of Misch's (1949) dictum that plutonic activity is confined to eugeosynclinal regions.

GENERAL REMARKS ON STRATIGRAPHY AND STRUCTURE.

Our knowledge of the stratigraphy of this region of New South Wales and north-eastern Victoria is still only fragmentary, mainly because of the rarity of fossils and the overall lithological uniformity of the metasediments. No fossils have been found in the area under discussion, but at several localities in this belt graptolites of upper

Ordovician (usually Eastonian) age have been recorded. Rather poorly preserved graptolites occur in black slates near Moorong Trig. Station, a few miles west of Wagga Wagga (Joplin, 1945) and at Carboona Gap (about half-way between Tumbarumba and Jingellic; found by R. A. Keble, noted by Sherrard, 1951). Graptolites have been found elsewhere in the same Ordovician belt both in Victoria and in New South Wales (Joplin, 1945). They also occur at Cooma (Browne, 1914). Gradations from graptolitic slates into more intensely metamorphosed sediments have been observed in Victoria and at Cooma, and as a result of such evidence the latter are now regarded as also being in part, at least, of upper Ordovician age. Early writers have referred these metasediments to a variety of ages, ranging from pre-Cambrian to Silurian and even Devonian. By analogy with other parts of the metamorphic belt it is believed that the metasediments of the present area are also partly of upper Ordovician age.





Text-figure 2.—Alkali/lime diagram for pelites from various parts of the world. Two average shales (from Clarke, *U.S. Geol. Surv. Bull.* 616) are marked by crosses. Pelites from the north-eastern Victoria-N.S.W. metamorphic belt (and from Cooma) are marked by black squares.

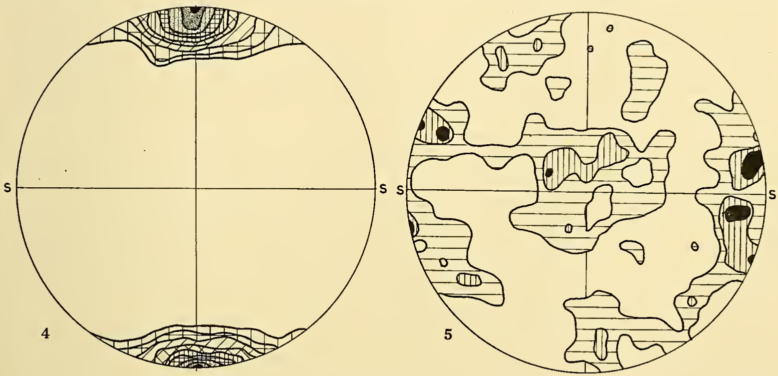
Text-figure 3.—ACF diagram illustrating chemical relations between normal (i.e. aluminous) pelites and the black siliceous pelites. Psammopelites and at least some of the grey-green siliceous slates fall between the two fields which are taken from Joplin (1945).

Point no. 1, This paper, Table 1, no. 4. 2, This paper, Table 1, no. 5. 3, This paper, Table 6, no. 8. 4, Joplin (1942), Table 5, no. IV. 5, Joplin (1942), Table 2, no. III. 6, Joplin (1942), Table 2, no. IV. 7, This paper, Table 6, no. 9.

No successful attempt has ever been made to subdivide stratigraphically the sediments of this metamorphic belt. At Cooma, Joplin (1942) separated the upper Ordovician into the Coolringdon Beds and the Binjura Beds. The former characteristically have black siliceous slate and display low-grade metamorphic features, whilst the Binjura Beds consist of more aluminous pelites and psammopelites and exhibit a much greater range in metamorphic grade. The Coolringdon Beds are regarded by Joplin as lying on top of the Binjura Beds, but the opposite view is favoured by Browne (1943). Possible equivalents of the Binjura Beds were noted at Albury (Joplin, 1947), but analogues of the Coolringdon Beds have not been found. In the Wantabadgery–Adelong–Tumbarumba area the metasediments have not been subdivided into such units. The higher-grade rocks here are quite similar to the Binjura Beds at Cooma, but there does not appear to be any extensive development of lithological equivalents of the Coolringdon Beds.

The thickness of the sediments in the main metamorphic belt (north-eastern Victoria, Albury, Wagga Wagga, etc.) is not known, but it seems reasonable to expect that it is much in excess of that given (2,500 ft.) for the Gisbornian, Eastonian, and Bolindian in the Australian upper Ordovician type-area, north-west of Melbourne.

Over most of the area examined the metasediments display a remarkable uniformity of strike which is, in general, parallel to the north-north-west–south-south-east trend of the whole metamorphic belt. A notable exception to this rule is found along the Murrumbidgee River between Oura and Wantabadgery, where the strike swings round sympathetically with the margin of the Wantabadgery granite mass. Cleavage and/or schistosity have been induced in most of the metasediments but bedding features are rarely destroyed. Bedding and cleavage or schistosity are often coincident but this is not universal (cf. Crohn, 1950). Lineation, though not always common in the low-grade rocks, may become an obvious feature in the knotted schists. Both a-lineation and b-lineation have been seen, though usually not in the same locality. The a-lineation is of some interest. In the Mundarlo district, for example, lineation is almost always at a high angle to the horizontal. Fold axes, where they can be seen, are commonly much more flat-lying and the impression one gains is that the lineation is about normal to the fold axes. Boudinage structures have been noticed in this area (Vallance, 1951) with the flattened "barrels" lying nearly horizontal on the steeply-dipping bedding



Text-figure 4.—Fabric diagram based on 200 poles normal to the (001) cleavage of biotite from a knotted schist zone psammopelite. The schistosity plane is marked and the plane of the projection is normal to the lineation. Contour intervals (in percent.) 32-25-20-15-10-8-4-2-1-0.

Text-figure 5.—Fabric diagram based on 300 poles of optic axes of quartz from same rock as Text-fig. 4. Contour intervals (in percent.) 3-2-1-0.

planes and with a lineation (a-lineation) across the boudins in the direction of extension of the beds. The fabric (Text-fig. 4) of a rock from the same locality as the boudins indicates a remarkable preferred orientation of mica flakes. The patterns displayed by the optic axes of quartz grains (Text-fig. 5) and the mica cleavages suggest some "flattening" of the rock due to pressure across the schistosity. It seems not unreasonable to associate this with the possible development of boudinage due to tectonic flowage in the a-direction (normal to the fold axes).

Lack of good, continuous exposures makes it difficult to develop the overall structural picture in this area. In general the evidence points to a high degree of fairly close folding (perhaps not truly isoclinal) in the metasediments. Steep dips are the rule, but often little reliance can be placed on them because of the extensive hill-creep.

Despite Tattam's (1929, p. 10) remarks on the lack of strike faulting in the north-east Victorian metamorphic complex it does appear to have been rather important in the present area. Local small-scale strike faults may be seen in such exposures as road cuttings, although they may not be otherwise apparent on the ground. In the Tumbarumba district there is evidence of a considerable fault which has brought the Green Hills granite and low-grade metasediments into juxtaposition. A remarkably straight ridge of siliceous (silicified (?)) sediments trending north-north-west from Tumbarumba probably represents the fault line. From what evidence has been obtained the fault is thought to dip steeply to the east and perhaps dies out along the strike to the west of Westbrook. The suggested fault has removed from sight the middle- and high-grade metamorphic zones, but the extent of the movement may not be very great because of the apparent narrowing of the zones in this region. The very matter of this restriction in width of the zones may be related to further strike faulting (or perhaps to a marked steepening of the margins of the granite mass).

Whether the whole area is dominated by a major fold structure on which the local tight folding was superimposed (as suggested by Howitt in Victoria, and by Joplin (1943) at Cooma) is a question which has not been answered.

Metamorphic Zones.

In the course of this work it has been established that certain mineralogical and textural variations in the metasediments take place with remarkable regularity as some of the granite masses are approached. With increase in metamorphic intensity the slates become more lustrous and micaceous and pass through phyllites into mica schists. These schists may develop porphyroblasts (knotted schists) and eventually grade into granulites or even migmatites. It has been found possible to divide the metasediments of this series into zones based on mineralogical and textural criteria. Under favourable conditions such zones may be plotted on the map.

The pioneer in this type of work was George Barrow (1893, 1912), who divided the Dalradian of the south-east Highlands of Scotland into seven zones as follows (from low to high grade): (1) zone of clastic mica, (2) zone of digested clastic mica, (3) zone of biotite, (4) zone of garnet, (5) zone of staurolite, (6) zone of kyanite, and (7) zone of sillimanite. Tilley (1925) later combined (1) and (2) as a zone of chlorite, and made the garnet zone more specific by using almandine as the index mineral. It is interesting to notice, as Joplin (1947, p. 91) has pointed out, that Howitt in 1889, whilst working at Omeo, was thinking along the same lines as Barrow.

Barrow's series was a great advance, but it is quite evident that it can be specific only for a certain isochemical series under the impress of metamorphism comparable with that which affected the Dalradian. As might be expected, Barrow's sequence has been observed in other parts of the world, but exceptions to it are, at least, equally widespread and numerous. These apparent anomalies make it necessary to consider variations in metamorphic grade against a more comprehensive classification such as is provided by the principle of metamorphic facies. In this way Barrow's sequence acquires its true perspective and it becomes clear that it cannot, by itself, be used as a general classificatory system. On the other hand, a relatively simple system of zones, based on the same style of reasoning as Barrow's zones, is usually more readily applied in the field than are the more complex mineral facies based on the phase rule. Thus in the present study a series of fairly obvious mineralogical and textural features which can be plotted on the map and correlated with the facies concept have been selected as zonal markers.

In the lowest grade of metamorphism in this area, chlorite may be produced along with sericite (muscovite). The zone in which such minerals are stable is here called the low-grade zone (= chlorite zone of Joplin, 1942). Next in the metamorphic sequence brown biotite appears and any chlorite present tends to be converted to biotite; this development of brown biotite marks the outer limit of the biotite zone. Porphyroblasts of andalusite or cordierite may be formed in the two-mica schists and these typically occur in the zone of knotted schists (andalusite zone of Joplin, 1942). Near the Green Hills granite mass the knotted schists pass into more granular rocks in which sillimanite may appear. Against the granites these granulites may grade into mixed rocks or migmatites. The granular rocks and migmatites correspond to what Joplin (1942) has called the permeation- and injection-zone rocks at Cooma. It has not been considered practicable to separate the high-grade rocks of this area into two comparable zones and thus they are here regarded as members of one high-grade zone. Correlation of these zones with the facies concept will be attempted after the zones and their characteristic metasediments have been described.

I. Low-grade Zone.

Low-grade metasediments outcrop over a large part of the Nangus district and extend in a south-easterly direction along the strike to the Tumblong State Forest (just north of Bangandang Trig. Station). Apparently similar rocks are found to the east along the railway line between South Gundagai and Tumblong. On the western side of the area they are developed in a belt extending from Lower Tarcutta through Tarcutta and Humula to Tumbarumba. On the geological map (Plate v) the low-grade rocks occupy all the area of metasediments outside the biotite isogradal line.

(i) *Pelites.*

Pelites in the low-grade zone are commonly fine-grained, buff- to grey-coloured rocks with a good slaty cleavage. Most of them have acquired a certain lustre as a result of the metamorphism and with increase in grade merge into phyllites and schists.

Apart from occasional white mica flakes few of the mineral constituents of these rocks are visible to the naked eye. Sericite (muscovite) and quartz are the chief constituents; chlorite is less common. The platy minerals are characteristically arranged to produce a schistosity. Although the grain-size is very small it would appear that all the mica has been recrystallized. The tiny flakes of sericite are usually colourless to pale green. With increase in grade (i.e. towards the biotite zone) two separate micas may appear; white mica (muscovite) and a greenish type which in the next zone passes into biotite (cf. Tilley, 1925). Increase in grain-size accompanies increase in grade.

Fine quartz granules between the mica flakes have presumably been derived from the detrital quartz by recrystallization. Chlorite, where it occurs, is found as dimensionally oriented flakes of rather variable size. The pleochroism is usually weak, most commonly from pale green or nearly colourless to yellow-green; $\beta = 1{\cdot}585$ (one determination); optical sign doubtful; birefringence varies to ca. 0·008; anomalous brownish interference colours are not unusual. Such flakes may carry inclusions of iron ore, micas, tourmaline and zircon.

Chlorite is not as abundant here as it is in the low-grade pelites at Cooma. The reason for this is not readily apparent. In composition the low-grade rocks resemble those from Cooma, although in some cases the pelites of the present area have a slightly higher soda content. Excess alkalis might tend to give rise to mica (sericite) rather than chlorite when magnesia is not abundant. Barth (1936) found that there was no development of pre-biotite chlorite in Dutchess County, New York. This matter was briefly considered by Bailey (1937), who suggested that it may have been due to a combination of high soda content of the rocks and "exceptionally dry conditions of metamorphism". Bailey's suggestion, particularly with regard to the soda content, has not been clearly established. The question is not settled, but the reason for the absence or paucity of chlorite in some cases, at least, may be more physical than chemical.

The grey-green to buff siliceous slates and phyllites (page 94) are often not readily distinguishable in hand-specimen from the less siliceous pelites. In the low-grade zone these siliceous rocks are widespread, particularly to the south of Nangus, and south-east of Borambola through Tarcutta to Tumbarumba. The main difference in thin section between these rocks and the normal aluminous pelites is in the proportion of quartz to mica and chlorite. In other respects they resemble the normal pelites.

Fine-grained black siliceous rocks occur within this zone near Tarcutta Hill to the south of Yabtree Trig. Station. These rocks are more often blocky and jointed than slaty, and may be associated with cherts. Highly siliceous cherts occur just west of Tumbarumba. The essential minerals of the black rocks are quartz and sericite with varying quantities of such accessories as iron ore and carbonaceous matter. Chlorite is rarely found. Gaps suggesting negative pyrite crystals are sometimes seen but fresh pyrite is quite rare. Isotropic material in the base of some of these siliceous rocks may be similar to what Joplin (1942) has suggested to be massive chalcedony or very fine quartz.

(ii) *Psammopelites and Psammites.*

Although the psammopelites are the commonest rocks in this area, they may profitably be studied after the pelites. Their mineralogy is similar to that of the pelites (except for the quartz/mica–mineral ratio) and thus they should be expected to reflect the mineralogical changes seen in the pelites.

Recrystallization has occurred to varying degrees in all these sandy rocks, but in no case have the signs of their clastic origin been obliterated. Quartz and felspar grains of somewhat irregular shape and size are commonly embedded in a much finer matrix of sericite, quartz, and some chlorite. The matrix behaves much as do the pelites mentioned previously. As a rule the more argillaceous psammopelites acquire cleavage and schistosity before the sandier types. The larger quartz and felspar grains tend to be oriented along the schistosity.

The quartz grains may display undulose extinction and with increase in metamorphic intensity they become granulated. This granulation has been noted in the low-grade zone but, as a rule, the larger grains retain their clastic appearance at least as far as the knotted schist zone. Both twinned plagioclase (usually oligoclase or oligoclase-andesine) and untwinned orthoclase may be present in the "sand" fractions of these rocks. Often the felspar is rather fresh, but there is an obvious tendency with increase of metamorphic grade for its conversion to such minerals as sericite and albite. Tourmaline, zircon and iron ores are the chief accessories.

(iii) *Jaspers.*

Immediately to the west of the village of Nangus is a low ridge composed in the main of red jaspers. Southwards, these rocks continue across the Murrumbidgee River but gradually fade out along the strike into low-grade rocks laced with quartz veins. It seems probable that the jaspers also die out to the north, but mapping was not extended in that direction. To the east and west these rocks are flanked by low-grade metasediments, but a blanket of alluvium obscures the exact relations between them. The age, origin, and metamorphic significance of the jaspers have not been finally settled, but as they outcrop entirely within the low-grade zone they are considered here.

Typically the jaspers are fine-grained, hard siliceous rocks with a rather patchy appearance and varying in colour from bright red to black (even in the same hand-specimen). They outcrop as large blocks showing practically no sign of any regular structure apart from jointing. Slickenside-markings are not unusual on some of the more platy-jointed types.

Under the microscope the essential minerals are seen to be quartz and haematite. Sometimes a little magnetite is present. Commonly the haematite is veined by granular quartz and in places the rock has the appearance of a haematite-breccia with the iron ore patches sharply separated by granular quartz. The quartz, though always granular, has a distinctly variable grain-size. Some of it is finely dusted with haematite whilst other, later, quartz may be perfectly clear. The larger grains may show undulose extinction. Haematite occurs mainly as irregular, dark, opaque patches, as smaller opaque grains and occasionally as minute red translucent euhedral plates.

Accessory constituents are variable, but perhaps the commonest is a yellow-green chlorite which may be sparsely scattered through these rocks. Apatite has been doubtfully recognized and calcite is present in some cases. One specimen has very fine needles of a pale yellow to orange-yellow; feebly pleochroic mineral with rather high relief and strong birefringence. Extinction angles vary up to about 20°; the needles seem to be length-slow. The mineral may be an iron-rich amphibole, but its presence here is very puzzling in view of the low grade of metamorphism. Amphiboles of the grunerite-cummingtonite series are known from metamorphosed jaspers (Miles, 1946) and other iron-rich rocks, but they are normally produced only in the higher grades of metamorphism (see Tilley, 1936). There is a possibility that a small mass of hornblende-augite-porphyrite might have locally affected the jaspers at Nangus, but this has not been established.

Occasionally specimens have been noted in which haematite wraps around quartz grains, the arrangement giving the impression that the iron oxide is in process of replacing a sandy rock. Generally compact, the jaspers at times have dark porous patches of haematite and limonite along fracture planes. In extreme cases cavities may be lined with botryoidal iron ore. These colloform growths are usually composed of radiating goethite with striking concentric zones. Haematite may form the cores of such growths, which are no doubt due to the hydration of the ferric oxide.

One of the jaspers has been analysed and the result is given in Table IV. For comparison, jaspers from Anglesey and Western Australia are included. Analyses 1 and 2 display a remarkably specialized composition—mainly silica and ferric oxide. The third rock quoted has a roughly comparable silica content but is really a quartz-rich ironstone of different origin from the first two.

TABLE 4.

Jaspers.

	1	2	3
SiO_2	85·51	88·07	77·94
Al_2O_3	0·21	1·31	0·24
Fe_2O_3	12·94	10·75	9·47
FeO	0·61	—	7·72
MgO	tr.	—	1·91
CaO	tr.	—	1·17
Na_2O	0·09	nil	0·04
K_2O	0·05		0·10
H_2O+	0·18	—	0·41
H_2O-	0·20	—	0·20
TiO_2	nil	—	nil
P_2O_5	tr.	—	0·09
MnO	0·30	—	0·39
FeS_2	—	—	0·04
CO_2	nil	—	0·79
	100·09	100·13	100·51

1. Red jasper. Por. 259, Par. of Tenandra, Co. Clarendon. Anal. T. G. Vallance.
2. Gwna-jasper. Mona complex, Anglesey, Wales. Anal. J. O. Hughes. *Geol. Surv. England and Wales, Anglesey Memoir*, I, 1919: 87.
3. Siliceous jaspilite. Southern Cross area (W.A.). Anal. H. Bowley. *Geol. Soc. London, Quart. Jour.*, 102, 1946: 142.

The slates and phyllites near the jaspers often have signs of intense deformation and silicification. Plate vi, A, illustrates one such rock which has been contorted and ruptured, apparently after the development of the schistosity. Limonite frequently stains the fractures, which are usually filled by patches of granular quartz. The more intense the deformation, the more granular quartz is deposited. Rocks approaching silicified phyllite-breccias tend to be produced by this action, but their original sedimentary nature can usually still be recognized.

Various theories of origin have been proposed to account for such rocks as jaspers and it appears that the question is by no means uniquely solved. The following are among the hypotheses advanced: (1) Original deposits. This origin was ascribed by Greenly to the Anglesey jaspers which he thought to be radiolarian cherts. The Nangus jaspers have no fossils and no traces of bedding—features often found in original sediments of this type. Sedimentary ironstones for the most part have less silica than these jaspers. (2) Replacement of earlier-formed rocks. (*a*) Surface effects. Zealley (1918) suggested that certain jaspers in Rhodesia were surface features due to the solution and deposition of silica and iron during weathering. There is no evidence that the

Nangus rocks are superficial. (*b*) Metasomatic action related to magmatic bodies. This theory was applied by Van Hise and Leith (1911) to account for certain jaspers. The jaspers of the Bowling Alley series of the Great Serpentine Belt (N.S.W.) were believed by Benson (1915) to be due to the action of adjacent spilite and keratophyre masses. At Nangus, a few small porphyrite masses are associated with the jaspers but they are hardly extensive enough to have been responsible for the production of all the jaspers. In any case, similar rocks near Oaky Creek, south of Nangus, are associated with more normal metasediments and have not jasperized them. (*c*) Jasperization related to serpentine. This relation has been suggested by several workers; some of the Woolomin jaspers have had such an origin ascribed to them (see Browne, 1950, p. 206). A small patch of serpentine-bearing rocks has been found south of Nangus, but as these rocks themselves have been silicified and are so limited in extent they could hardly have provided sufficient silica and iron to satisfy the jaspers. Osborne (1950) has noted the association of jasper and serpentine at Wood's Reef, N.S.W. He believes that "medium to high-temperature (hydrothermal) solutions containing silica and iron" have caused jasperization of the Tamworth series and stresses the importance of the siliceous nature of the original sediments and their tectonic setting as determinative factors in the jasper-formation. This view leads us to (*d*) solution and re-deposition of silica and iron in the metasediments during a period of dynamic activity. The case has already been cited of the deposition of granular quartz in the deformed and smashed metasediments near the jaspers. The evidence of the jaspers themselves indicates that the formation of haematite preceded the silicification. It is probable that the silicification affected a greater area than did the haematite enrichment. The reason why all trace of regular directional structures such as schistosity should be obliterated in the jaspers is not known. It is certainly strange that this should be the case if intense dynamic action were involved in the jasperization (a possible explanation of this is that the final stage of the jasperization took place under rather static conditions and complete replacement might mask all such structures; only where silicification alone has taken place do the directional features become apparent). Benson (1918) in discussing the Eastern series jaspers of the Woolomin district, N.S.W., stated that "they result from intense silicification along zones of shattering, and are not primary deposits". If the Nangus jaspers are iron-enriched, silicified sediments, as is tentatively suggested here, it is a matter of no little difficulty to account for the components of the sediments which would have been displaced.

The age of the jasperization is not much more definitely known than is its origin. If the jasperization and the silicification of the neighbouring metasediments are related, then the jasper-formation is post-schistosity, i.e. it occurred at least after the "schistosity-forming" phase of the metamorphism. On the other hand, some of the igneous bodies associated with the jaspers have not been jasperized, yet they have suffered low-grade metamorphism. To the south apparently comparable rocks of igneous origin display an increase in grade sympathetically with the metasediments. It is therefore suggested that the jaspers were formed during the period of metamorphic activity but that they do not belong to the first phases of the action.

(iv) *Limestone and Serpentine Rock.*

Limestone has been found at one locality (T.S.R. 44,174, Par. Mundarlo, Co. Wynyard) in this region. It occurs on the south bank of the Murrumbidgee River south of Nangus, and was once quarried and burned for lime. The deposit is recorded by Carne and Jones (1919) but their description is rather inaccurate. Their report classifies the associated rocks as "clayshales, mudstones, and sandstones", whereas, in actual fact, highly siliceous rocks, often akin to jaspers, occupy the area near the limestone. The limestone appears to form a lens following the major strike of the region, but the rock has not been traced far from the river-bank. A deep red soil covering obscures its southerly continuation.

The rock is a white, rather massive, fine-grained marble which, while not dislocated on the same scale as the surrounding rocks, may show some signs of cracking—the cracks usually being emphasized by limonite stains. A few pyrite cubes may be found at times but, as is indicated by the analysis (Table 5), the limestone is generally a very pure calcium carbonate rock. It is a strange fact that in an area of intense silicification the limestone does not appear to have suffered much addition of silica.

In close proximity to the limestone, often between it and the jaspers, there are a few outcrops of a patchy green rock which, although apparently fibrous, is compact and hard. When sheared, the rock develops a poor cleavage and becomes much jointed. Surface weathering produces a red clayey soil and this covering often masks critical boundaries.

These fine-grained green rocks consist mainly of fibrous antigorite and chalcedony, with smaller amounts of talc, iron ore, and sometimes carbonate minerals. The antigorite often has a distinctly variable grain-size and not infrequently relatively large aggregates

TABLE 5.

	1	2	3	4
SiO_2	0·44	74·41	46·44	46·44
Al_2O_3	} 0·91	2·35	10·12	4·85
Fe_2O_3		5·68	3·98	11·75
FeO		0·30	8·30	0·61
MgO	0·16	10·86	21·32	22·46
CaO	55·27	0·22	6·54	0·45
Na_2O	0·03	0·15	0·78	0·30
K_2O	0·09	0·18	0·28	0·36
H_2O+	} 0·08	4·21	1·41	} 12·60
H_2O-		1·87	0·08	
TiO_2	—	tr.	0·20	—
MnO	—	0·09	0·12	0·18
CO_2	43·03	—	—	—
	100·01	100.32	99·57	100·00

1. Limestone (fine-grained marble). North-east corner of T.S.R. 44,174, Par. of Mundarlo, Co. Wynyard. Anal. T. G. Vallance.
2. Siliceous serpentine-bearing rock. North-east corner of T.S.R. 44,174, Par. of Mundarlo. Anal. T. G. Vallance.
3. Ultrabasic inclusion in Wantabadgery granite. Por. 52, Par. of Mundarlo. Anal. T. G. Vallance.
4. Analysis No. 2 recalculated to 100% on the basis of 46·44% SiO_2.

with common orientation are associated with finer criss-cross patches (as in Plate vi, B). Colourless or stained yellow (optical sign –ve; length-slow; parallel extinction; birefringence about 0·007) the antigorite appears to alter to fine aggregates of a flaky mineral (strong birefringence; parallel extinction; biaxial –ve; small 2V; length-slow) which is probably talc (the paragenesis suggests talc rather than muscovite). The alteration is at best only local and patchy. Silica fills cavities and veins and, in general, gives the impression of having been added to the rocks. It is usually chalcedonic and has an aggregate appearance. The silica-filled cavities are sometimes lined with small concentric growths of an unidentified mineral (colourless; refractive index lower than balsam; high relief; almost isotropic). Limonite commonly stains the antigorite, and magnetite may appear as small granules. Carbonate minerals occur in some cases but often are not abundant.

In Table 5 is given an analysis of a rock of this type. The most remarkable feature is the high silica content coupled with an abnormal amount of magnesia.

There are perhaps two possible theories of origin: that the rocks are derived (1) from carbonate rocks, or (2) from ultrabasic igneous rocks. Serpentinization of calcium carbonate rocks by magnesia-silica metasomatism has been mentioned by various authors. In the present instance there seems to be no ready source of magnesia necessary to convert the limestone and so this mechanism must be rejected. Eskola (1951) has discussed the derivation of serpentine rocks from dolomites by the addition of silica to the carbonate rocks. In that case the excess lime is removed as bicarbonate and would be eventually deposited as calcite. Where lime is less free to escape from the system, low-temperature silica metasomatism of dolomite would produce amphibole. At Mundarlo, the carbonate rock now exposed is definitely deficient in magnesia and as far as could be determined in the field there are few reaction features between the limestone and the serpentinous rock. If the latter were derived from dolomite little trace of the parent material remains. There is, however, at least one argument against the serpentine rock being derived from this source. These rocks appear to occur within the low-grade zone which includes pelites characteristic of the muscovite-chlorite subfacies of the Greenschist Facies (see page 118). In such an environment the association dolomite-quartz is stable (Turner, 1948, p. 96). There is no evidence to suggest an increase in metamorphic grade in proximity to the serpentine rocks.

The mineralogy of these rocks suggests that the silica content is not all original. If we ignore the high silica it can be seen that the mineral assemblage is such as might be expected to result from the low-grade metamorphism of, say, a silica-poor, magnesia-rich (ultrabasic) igneous rock. The only ultrabasic rock known in this area occurs as a large inclusion in the Wantabadgery granite near Mundarlo (serpentine derived from ultrabasic rocks occurs to the east in the vicinity of Gundagai). The composition of the Mundarlo inclusion is given in Table 5. This rock has been rather strongly metamorphosed and, whilst not being strictly comparable with the siliceous serpentine, it does provide the basis for an interesting comparison. The silica-rich analysis has been recalculated to 100% on the basis of the SiO_2 content of the inclusion. The result (which is not far from the composition of antigorite, although MgO is rather low), when compared with the analysis of the inclusion, indicates roughly equivalent iron and magnesia but dissimilar alumina and lime contents. In the absence of more definite evidence it is suggested that the antigorite-bearing rock was derived from ultrabasic igneous material in sills by processes of low-grade metamorphism and, later, silicification. The reaction antigorite $\rightarrow$ talc may have been related to the latter process:

$$\underset{\text{antigorite}}{Mg_3(OH)_4Si_2O_5} + 2SiO_2 \rightarrow \underset{\text{talc}}{Mg_3(OH)_2Si_4O_{10}} + H_2O$$

G. A. Macdonald (1941) indicates that the conversion of serpentine to talc is the first stage in the progressive metasomatism (i.e. silica metasomatism) of serpentine in the Sierra Nevada of California.

II. Biotite Zone.

The outermost isogradal line drawn on the map represents the incoming of brown biotite in the phyllites and schists. As a general rule this biotite isograd displays a remarkable parallelism to the margins of the Wantabadgery and Green Hills granite masses. Near the northern end of the Ellerslie mass the isograd turns to the east, apparently following the outline of that mass. Little or no change in the biotite zone seems to occur near the Belmore mass.

The zone appears to be widest where it extends across the regional trend of the country. It attains its maximum surface width (about three miles) in the Borambola district. Between Rosewood and Westbrook the zone becomes quite restricted and disappears entirely further south. Biotite has been noticed in phyllites near Humula Trig. Station and to the west near the Kyeamba adamellite. This suggests an increase in metamorphic grade in this area but, as only reconnaissance mapping has been undertaken west of Humula, isogradal lines have not been plotted.

Biotite zones of comparable metamorphic status have been found at Cooma (Joplin, 1942) and at Albury (Joplin, 1947). At Omeo (Victoria), Crohn (1950) mentions a biotite zone but he has not plotted its limits on the map.

Certain lithological types—jaspers, limestone, and silicified serpentine—found in the low-grade zone do not occur here, but otherwise the rock types of both zones are comparable.

(i) *Pelites.*

By this stage of the metamorphism most of the pelitic rocks merit the title fine-grained mica schist. Cleavage and schistosity are usually obvious; finely plicated schistosity is somewhat unusual. The increase in metamorphic grade generally produces a darker colour (commonly dark olive-green) in these pelites relative to that of the lower-grade pelites. Colour variation is, however, not a sufficiently reliable criterion to be specific as a zonal indicator. In actual fact, the mapping of the biotite isograd has proved to be one of the most tedious operations associated with these studies because the appearance of biotite can only be determined with the aid of a microscope.

Mineralogically, these pelites contain biotite, muscovite, quartz, a little felspar and chlorite, and the common accessories zircon, tourmaline, iron oxides and rutile. Biotite, the index mineral for the zone, occurs as small light brown to brown (the colour tends to deepen somewhat with increase in metamorphic intensity) flakes aligned along the schistosity. In the higher-grade parts of this zone there may be a tendency for biotite porphyroblasts to be formed across the schistosity and this feature is most marked in the mica-rich rocks. Pleochroism is strong and for biotite towards the upper (metamorphic) limit of the zone a typical scheme is: X = very pale yellow-brown; Y = dark red-brown; Z = dark red-brown; Z = Y $\gg$ X. Greenish mica, mentioned as occurring in some low-grade pelites, may continue into the biotite zone but at an early stage gives place to brown biotite. Chlorite, likewise, is almost all converted to biotite quite soon after the biotite isograd is reached. Muscovite is an important constituent of these schists but apart from an increase in grain-size is not much different from its low-grade counterpart.

Quartz is finely granular and commonly oriented along the schistosity. Felspar may appear as an accessory. One unusual rock contains an abnormal amount of finely granular felspar (the analysis is given in Table 3, no. 2). The high soda content is accounted for by the presence of small untwinned albite grains. Albite in relatively low-grade schists has been attributed to a variety of causes, including addition of soda (Clough; see Harker, 1939, p. 212). Mica-schists rich in soda and lime occurring at Sulitelma are mentioned by Vogt (1927), who suggested that they were related to an incomplete weathering of the source material. Similar rocks are found elsewhere in the Caledonides of Scandinavia, where, as in Scotland, there appear to be two schools of thought on the matter of their origin. Some authors (e.g. Strand, 1951) favour a metasomatic origin for the sodic felspar in such rocks. In view of the local development of the albite-bearing rocks in the present case the best explanation seems to be that the felspar is of detrital derivation. It is interesting to note that here there is no tendency for albite porphyroblasts to form, whilst in the Dalradian of Scotland such large albites may appear even before biotite (Harker, 1939). Harker apparently associated the porphyroblast development with stress influence.

Odd grains of tourmaline are not uncommon. Variable in colour, the blue-grey is more commonly found than the brown type. Graphite flakes occur in some aluminous pelites. Where carbonaceous material becomes abundant it is usually associated with chlorite and a pale yellowish-green mica as well as sericite, quartz and the common accessories with perhaps a preponderance of iron ore. Such rocks may occur near the non-carbonaceous pelites in which brown biotite and muscovite are abundant. Comparison of the two assemblages suggests a lag in the response to the metamorphic variations in the first case relative to the second. This phenomenon seems reasonably to be explained by the inhibitive action of the carbon (see Harker, 1939, p. 224; and Turner, 1948, p. 158).

In general, the siliceous pelites reflect the mineralogical and textural changes observed in the more aluminous types. Brown biotite appears at roughly the same stage in both cases. Exceptions to this rule are provided by the black siliceous rocks which, as might be expected from their carbon content, show a distinct lag. The black siliceous types are not extensive in the biotite zone but they do pass into it near Tarcutta Hill. Quartz, sericite, chlorite, a little biotite, iron ore and carbonaceous matter constitute the greater part of these rocks, which are not unlike their counterparts in the low-grade zone. Biotite is not common and in some cases is quite absent. Occasionally pale greenish mica flakes are apparent. Quartz is the major constituent of all these rocks. It is usually finely granular but distinct grain-size variations are common even in the one thin section. Quartz veins frequently occur and the coarser quartz-rich patches are often associated with them. Some of these veins in the more massive rocks display intricate fold-patterns (cf. ptygmatic veins in granitized regions). Where the carbonaceous matter is present in patches the carbon-rich portions have the finest-grained quartz associated with them. Local haematite staining is rather common and some, at least, of the iron oxide has been derived from the breakdown of pyrite.

(ii) *Psammopelites and Psammites.*

The mineralogical changes typifying the pelites of the biotite zone also occur in the sandier rocks. Chlorite and green mica are converted to biotite just as in the pelites. Most of these sandy rocks have sufficient matrix material available to produce the index mineral biotite and are thus quite useful for zoning purposes. Biotite appears to form in the sandy rocks earlier than in the pelites but the lag is never great. Harker (1939, p. 224) considered that the more psammitic rocks should lag behind the pelites during progressive metamorphism, but the opposite relations found during the present study also obtain at Cooma (Joplin, 1942, p. 170). Ray (1947) suggests that "more quartzose schists are prone to indicate by virtue of their inherent rigidity a slightly lower grade of metamorphism than a pelitic schist showing the same index mineral". In the present case (as at Cooma) the metamorphism has an important thermal factor (Ray and Harker were considering almost exactly equivalent zonal sequences) which may overcome the "inherent rigidity". Joplin (1942) suggested that the pelite lag might have been due to enhanced diffusion related to the presence of pore-fluid in the sandy rocks.

Quartz is the major constituent of these rocks and is usually associated with muscovite, biotite, chlorite and green mica (near the biotite isograd) and the usual accessories. Epidote has been noted as a rare accessory. As in the low-grade zone the large quartz grains tend to become granulated and recrystallized but original clastic characters often remain (preservation of original features has been observed in the biotite zone of the Woomargama and Burrumbuttock districts at Albury (Joplin, 1947); at Cooma they have usually been obliterated). Detrital plagioclase may survive well into the biotite zone, though it is definitely unstable under these conditions. The general tendency is, however, for the plagioclase to be replaced by albite.

III. Knotted Schist Zone.

With increase in metamorphic intensity the pelitic rocks acquire the appearance of knotted schists by the development of porphyroblasts. These "knotted" rocks are readily recognizable in the field and an isogradal line may be drawn joining the points where the porphyroblasts appear. Such an isograd was used at Cooma and Albury by Joplin to introduce a zone of knotted schists (at Cooma called andalusite zone) and to separate it from the biotite zone. Tattam and Crohn (see Crohn, 1950, p. 16), working on the Victorian end of the metamorphic complex, have noted the development of porphyroblasts of cordierite in biotitic schists. Crohn believes, however, that this feature "cannot be used to define a new zone" because of the difficulty of distinguishing between spots of incipient cordierite and micaceous aggregates due to retrogressive alteration of the cordierite. He therefore considers these rocks as members of the biotite zone rather than as characteristic of a separate zone. Whilst there may be some justification for Crohn's claim, my experience in this area has been that a knotted schist zone can be defined and mapped without undue ambiguity. The term knotted schist zone is used here rather than, say, andalusite and/or cordierite zone because it is often a matter of some difficulty to prove unequivocally which of these minerals was present originally as porphyroblasts.

Schists characteristic of this zone are found in proximity to the Wantabadgery mass except at its south-eastern end where high-grade rocks occur. A definite high-grade zone separates the knotted schists from the Green Hills granite mass. As in the case of the biotite isograd, the outer limit of the knotted schist zone roughly parallels the margins of the granite masses. Knotted schists occur along part of the northern end of the Ellerslie mass and have been traced as far as Bangandang Trig. Station. Again, like the biotite zone, this zone appears widest where it transgresses the regional strike of the metasediments. The eastern belt of knotted schists becomes increasingly narrow as one passes from south to north. The western (i.e. to the west of the granites) belt is widest to the east of Tarcutta and is more restricted both to the north and south. The Belmore mass has not had much effect on the knotted schist zone, for in many places knotted rocks do not appear at all and the granite comes into contact with biotite-zone rocks. Where the zone swings round sympathetically with the Wantabadgery granite it increases in width as it passes westwards and finally achieves a surface width of about five miles in the vicinity of Alfred Town. To the south-west of Westbrook the knotted schist zone narrows and finally disappears. South of Tumbarumba, along the valley of Tumbarumba Creek, fragments of knotted schists have been found in the tributaries draining the country to the west (Mt. Garland area). This seems to indicate that away from the fault line the knotted schists reappear in this southern area.

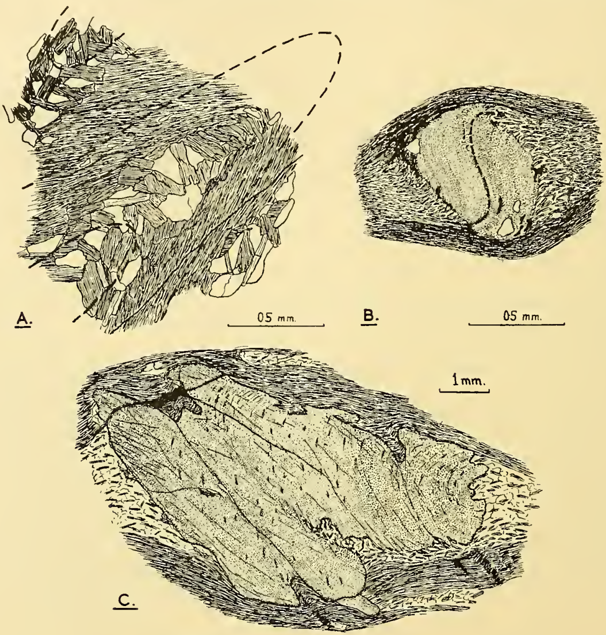
(i) *Pelites.*

The index feature of this zone is displayed typically by the pelites. With approach to the granite masses biotite-bearing schists become spotted by the incipient clots from which form quite rapidly the definite porphyroblasts responsible for the knotted appearance of the pelitic schists.

These pelites are highly lustrous and micaceous and not uncommonly display small-scale plications of the schistosity. The lepidoblastic base of these schists, although somewhat coarser, is comparable with the biotite-zone schists. Mineralogically they may be identical. Brown biotite, muscovite and quartz are the essential constituents with the same accessories as were noted in the biotite-zone schists. Biotite as well-developed flakes is of the strongly pleochroic brown or red-brown type: X = pale straw-yellow; Y = dark brown or red-brown; Z = dark brown or red-brown; $Z = Y \gg X$; $\gamma = 1{\cdot}639$; 2V very small. Generally the orientation of the flakes is parallel to the schistosity but with advancing recrystallization exceptions to this rule are not unusual. Occasionally large porphyroblasts (up to ca. 2 mm.) occur. Radioactive inclusions with associated pleochroic haloes are sometimes present. Muscovite blades and flakes aligned along the schistosity are abundant though often subordinate to biotite. Untwinned albite is an accessory in the knotted schists (at least in the outer parts of the zone). Potash felspar (untwinned), presumably a relic, has also been recorded on rare occasions. The presence of carbonaceous matter appears to cause a slight lag in the formation of porphyroblasts in the carbon-rich rocks.

The porphyroblasts usually stand out as dark knots on weathered surfaces. Traces of original idioblastic outlines are common but deformation has, in some cases, induced oval or almond shapes. The knots increase in size with approach to the granite margins and occasionally reach a length of from three-quarters to one inch. In all cases the porphyroblasts are more or less, often completely, altered to pseudomorphic greyish micaceous aggregates. Where cores of unaltered material have been found the original mineral is a clear, colourless variety of andalusite. The alteration products are mainly sericitic mica, with some biotite and occasionally a little chlorite. Biotite becomes more important in the altered knots of the higher-grade zone and usually has a minor role in the aggregates found in the knotted schist zone. In addition to micaceous aggregates with andalusite cores (and the more abundant comparable aggregates without such relics), pseudomorphs with a distinctly yellowish colour and relict poikiloblastic structure suggestive of pinitized cordierite are occasionally apparent. Fresh cordierite has, however, not been found in these rocks. Cordierite is recorded as an important constituent of knotted schists at Albury and in the Kiewa region of Victoria (Tattam, 1929), but in view of the extent of alteration in the present case it is difficult to assess the relative importance of cordierite and andalusite as porphyroblast minerals. The impression gained from an examination of thin sections would suggest that andalusite was the commoner of the two minerals.

Thin section examination often reveals that the knots have suffered a rotation which has tended to twist them into the plane of the schistosity. Rotation has therefore been greatest in the case of the porphyroblasts elongated directly across the schistosity. Text-figure 6, B, illustrates such a rotated porphyroblast. Patches richer in quartz and



Text-figure 6.

A. Camera lucida sketch of folds in a banded psammopelite showing undeformed biotite flakes in the crests and troughs of the folds. The dark lines in the pelitic bands represent post-crystalline shears.

B. Micaceous pseudomorph after andalusite (?) showing signs of rotation in a somewhat carbonaceous pelite.

C. Large pseudomorph after andalusite (?) showing signs of rotation as well as deformation due to post-crystalline shears. Undeformed biotite has, in places, crystallized along the sutured margin of the porphyroblast.

of coarser grain-size than the rest of the base are often developed on the "protected" sides of the porphyroblasts. Even when alteration to mica is complete the lines of inclusions in the pseudomorphs indicate the degree of rotation.

Study of these porphyroblasts leads to some interesting information concerning time relations of crystallization of the various constituents in these rocks. The factors causing deformation of the porphyroblasts may also have produced minor plications in the base of these rocks. Such plications are shown in Text-figure 6, A. It can be seen that on the inside of the folds the biotite has crystallized without distortion, suggesting a para-crystalline environment (cf. Read, 1949, p. 117). Text-figure 6, C, shows a porphyroblast which has suffered apparent post-crystalline deformation and associated with this are plications in the micaceous base displaying para-crystalline features. This suggests that the porphyroblast crystallized before the final crystallization of mica. Evidence of rotation is also seen in this porphyroblast, but the twisting apparently took place before the final deformation. Local shears in such rocks are not unusual and indicate stress influence even after the final mica crystallization. Although there is a tendency for the porphyroblasts to be aligned along the schistosity or rotated towards that plane, there does not appear to be much orientation of them parallel to the lineation. This may be because the lineation and the schistosity were initiated before the porphyroblasts formed, although it is clear that some stress influence and mica crystallization continued after this stage. The evidence available regarding the growth of these schists seems to point to a sequence of events rather like the following: (*a*) initial crystallization of micas producing a schistosity, (*b*) formation of porphyroblasts, and (*c*) final (minor) crystallization of mica. The suggested sequence may be related to variations in the thermal/stress balance during the metamorphism with the thermal peak coinciding with the porphyroblast formation.

These observations suffice to indicate that the metamorphic processes which affected these rocks were by no means simple and that the knotted schists as seen today were built in stages. It seems logical to regard all these stages as parts of the one overall metamorphism rather than as completely unconnected events. "The dictum of our master Becke", as Read (1949, p. 106) has remarked, must be rejected, for, in actual fact, simultaneous crystallization in schists is often the exception rather than the rule. It is reasonable to expect that the other rocks here bear cryptic evidence of comparable relations, for all of them have, in a general way, suffered the same metamorphism though they have been affected to different degrees.

Garnet has been mentioned as a constituent of certain schists in the Parishes of Cunningdroo and South Wagga Wagga by Whiting (1950). The former locality has been examined during the course of this work, but the occurrence of garnet has not been confirmed.

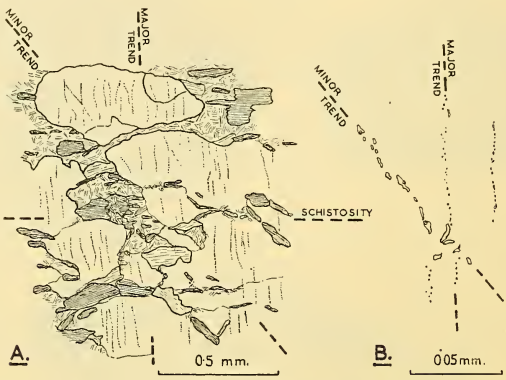
Black siliceous pelites appear to pass into a knotted schist zone environment to the north-west of Yabtree Trig. Station, but elsewhere they do not figure in this zone. Their composition precludes the development of andalusite or cordierite and thus they display no superficial indication of a change in metamorphic grade. Recrystallization merely causes an increased grain-size of the mineral constituents, which are the same as those found in comparable rocks of the biotite zone.

(ii) *Psammopelites and Psammites.*

The reaction of the sandier rocks to knotted schist zone conditions has been foreshadowed by the remarks already made. Quartz-rich psammites, poor in alumina, obviously would be unable to develop andalusite or cordierite no matter what the grade of metamorphism. On the other hand, it is quite conceivable that the more aluminous psammopelitic rocks could provide the materials necessary for the growth of andalusite or cordierite porphyroblasts, and this is exactly what happens in the rocks studied. The mica-rich portions of the banded psammopelites behave in the same manner as do the pelites themselves. The porphyroblasts make their appearance in such rocks before they do in the more homogeneous psammopelites. In the latter rocks the knots are quite comparable with those in the true pelites, except that where the supply of material is limited the grain-size of the porphyroblasts is diminished.

In the absence of "knots", a coarser grain-size is the only feature which might distinguish sandy rocks in this zone from their analogues in the biotite zone. Some of these metasediments still bear witness to their original clastic nature. Irregularities in size and a certain angularity of the sand grains may persist, but in the more intensely recrystallized parts of this zone such features often disappear. In the banded metasediments even such fine structures as graded bedding may be preserved into the knotted schist zone.

Quartz remains the dominant component of these rocks but a little felspar (plagioclase and relict K-felspar) may also be represented in the sand fraction. The orientation of the optic axial directions of quartz grains in a psammopelite from this zone has been represented in a fabric diagram (Text-fig. 5). Not infrequently the quartz grains in these rocks are traversed by lines of minute inclusions. These small inclusions are often opaque but occasionally larger examples are found which are rather irregular in outline and may contain small bubbles suggesting that the inclusions are liquid. Often the lines of inclusions can be proved to be end-sections of planes which display a remarkable constancy of orientation from grain to grain. Text-figure 7 gives sketches of these liquid inclusion planes which here cut across the schistosity. Tuttle (1949) has given an excellent discussion of the subject of liquid inclusions. He



Text-figure 7.

A. Camera lucida sketch of a knotted schist zone sandy rock showing planes of liquid inclusions, in the quartz grains, cutting across the schistosity.

B. Camera lucida sketch giving details of the inclusions in one of the quartz grains.

found that, at times, such planes have a remarkably uniform orientation over large areas. In Text-figure 7, B, it will be noted that there are two major orientations of planes of inclusions in these rocks and, applying Tuttle's (1949, p. 334) criteria, it can be seen that the "subordinate" group (minor trend) is probably of somewhat later age than the "dominant" group. It is quite obvious that there is no uniform relation between the orientation of these inclusion planes and crystallographic directions in the quartz. The planes of inclusions have certainly formed in the rocks after consolidation and cannot have been present in the original clastic grains. Tuttle believed that deformative processes were responsible for the development and uniform orientation of the inclusion planes in the Washington, D.C., area, and the same explanation seems reasonable in this case. No attempt has been made to apply petrofabric methods to this problem, but observations made suggest that such studies would bear fruitful results.

In addition to the sandy rocks with admixed clay as matrix material, odd bands of calcareo-arenaceous rocks are found in this zone. Mineralogically these latter rocks consist mainly of quartz and granular clinozoisite-epidote with subordinate dirty pale green amphibole and iron ore. Rocks of similar composition occur as inclusions in the Wantabadgery granite. It is interesting to note that it is such limy rocks which display boudinage structures at Mundarlo (Vallance, 1951). A few examples of psammopelites with abnormal lime have been found to the west of Bangandang Trig. Station. The development of crystals of pleochroic bluish-green or green amphibole along with brown biotite indicates an enhanced lime content. A rock containing a few subhedral, colourless garnets (associated with quartz and small aggregates of colourless amphibole) was also found here. This is the only occurrence of garnet in the country rock metasediments found during this study and is perhaps due to an unusual lime content; the rock has not been analysed.

IV. High-grade Zone.

When discussing the knotted schist zone it was mentioned that, whereas the knotted schists extended almost to the margin of the Wantabadgery granite, these schists were separated from the Green Hills granite by a zone of higher-grade rocks. The latter are typically more granular than the schists and may contain sillimanite. Near the granite contact they may become migmatites or injection rocks.

Actually these high-grade rocks do occur at the margin of the Wantabadgery granite mass but they are usually restricted to a zone often only a few feet wide. At the south-eastern end of this mass, however, such rocks are more extensive and a separate high-grade zone is mappable. Continuing southwards along the strike from Yaven Trig. Station, the high-grade zone widens rather remarkably until in the vicinity of Sargood Trig. Station it is about four to five miles across. The zone then narrows to the south, passing between the Green Hills and Belmore masses, and finally disappears some miles to the north of Tumbarumba. From the map it will be seen that the isograd defining this zone roughly follows the western margin of the Green Hills granite mass. Isolated masses of similar metasediments with the appearance of roof pendants occur at Hugel Trig. Station and in the area east of Tumbarumba (for example in the Nurenmerenmong Range).

The boundary drawn between the zone of knotted schists and the high-grade zone lacks the precision that characterizes the other isograds because of the personal factor probably involved in its mapping. The isograd has been drawn through points where knotted schists tend to lose their good cleavage and high lustre and acquire a more granular appearance. Joplin (1942) at Cooma was faced with a similar problem and remarked that "the boundary between this [i.e. the andalusite or knotted schist zone] and the succeeding permeation-zone was a somewhat arbitrary one, determined in the field by the appearance of slightly more granular and less schistose rocks". It will be noted that at Cooma the term permeation-zone was used to include the high-grade rocks which did not show injection by tongues of gneiss (injection zone). Because of the lack of a sharp contrast between these permeation and injection rocks in this area compared with Cooma the two zonal subdivisions have not been used in this study and all the rocks are considered in the one high-grade zone.

(i) *Pelites.*

Within the zone defined on the map there is a gradual change in the appearance of the rocks with approach to the granite contact. At the outer edge of the zone the rocks retain some schistosity and have knots apparently comparable with those of the knotted schists. In thin section, however, it may be seen that the knots have a slightly different appearance from those in the lower-grade zone. Typically, the knots, which in the knotted schist zone were composed of fine flakes of sericite, now consist of much coarser aggregates of mica flakes with a base of sericite and iron ore fragments. Muscovite blades are quite common, whilst a green biotite (pleochroic from pale yellow-green to medium greenish-brown) may also occur as less well-defined flakes (brown biotite is found in some cases). Both micas in the aggregates show little trace of preferred orientation which is in contrast to the mica of the base of these rocks. Brown pleochroic (pale straw to dark reddish-brown) biotite is the characteristic dark mica of the two-mica base. Occasionally unaltered cores of andalusite (clear and colourless) remain in the knots and the occurrence of both biotite and muscovite replacing it surely indicates an addition of bases from some external source. Compared with the altered porphyroblasts in the knotted schists these knots often have more diffuse boundaries against the micaceous base. Definite K-felspar and oligoclase have not been recorded here and in this respect these rocks differ from the higher-grade types in this zone.

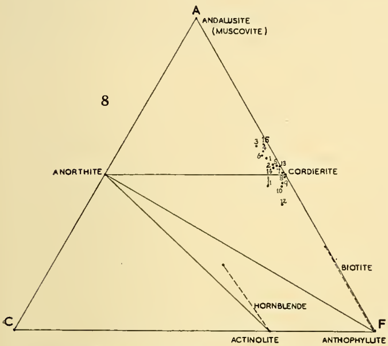
These rocks are followed in the metamorphic progression by varieties comparable with the spotted granulites of Cooma. Schistosity is much less obvious and the term granulite seems quite appropriate for such rocks. Their characteristic appearance is due to the dark micaceous aggregates or spots scattered through a much lighter-coloured base. With increase in grade the spots tend to merge with the base, but right to the granite contact some heterogeneity expressed by a mottled appearance is preserved. Red-brown biotite similar to that of the base becomes commoner in the micaceous patches and along with it may occur sub-radiating patches of pale chlorite flakes (pleochroic, pale yellow-green to mid brownish-green; parallel extinction; +ve (?); sometimes anomalous blue interference tints; length-fast). The chlorite is probably of a later age than the biotite. Blades of muscovite become more numerous and extensive as the granite is approached. Quartz is usually not abundant in the pelites and is commonly interstitial.

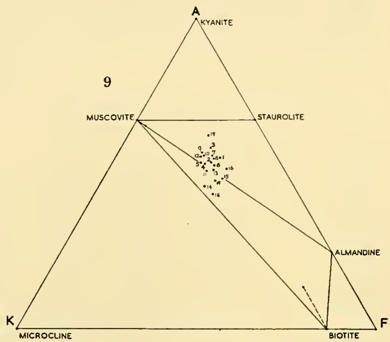
Andalusite may occur in these rocks as pleochroic (Z, Y = colourless; X = pale pink; pleochroism variable within a single grain) porphyroblasts with markedly ragged and poikiloblastic (mainly quartz and biotite inclusions) margins and almost inclusion-free centres. These porphyroblasts are often surrounded by zones enriched in biotite. Thin wisps and needles of sillimanite may be associated with the andalusite which, in contrast to the colourless andalusite of the knotted schists, shows no sign of alteration to micas. Joplin (1942, p. 180) has suggested that the pink pleochroic andalusite, occurring in a similar environment at Cooma, has been deposited from solution, i.e. it is of metasomatic origin. The colourless andalusite of the knotted schists is certainly of metamorphic origin. Whether any general relation exists between colour and origin of andalusite is not known, but in the literature there does seem to be a tendency for coloured andalusite to be recorded more often in granitic or metasomatic than in purely metamorphic environments (see for example, Hills, 1938; Santos Pereira, 1950). Cordierite poikiloblasts which are sometimes associated with the andalusite in these rocks are always more or less altered. In places the cordierite has subidioblastic outlines against quartz and the mica pseudomorphs have a markedly tabular form. The cordierite is sometimes large enough to be easily visible to the naked eye and may attain a diameter of from one-quarter to one-half inch. That the mica is replacing cordierite may be proved in many cases by the unaltered cores in the aggregates. It will be remembered that fresh cordierite was never found in the knotted schists and although the diagnosis of the mineral in that zone was always rather doubtful, it did not appear to be as abundant as andalusite. In the high-grade zone, however, cordierite is quite an important constituent of the pelites.

A glance at an ACF diagram (Text-fig. 8) on which the pelites have been plotted suggests that all of them (both knotted schists and high-grade rocks) should have abundant cordierite, yet it seems that the mineral becomes more important in the high-grade rocks. This brings to mind the suggestion of Potgieter (1950), who says that in rocks where both andalusite and cordierite are possible mineral phases the formation of andalusite might be favoured by a slight stress influence which would perhaps prevent crystallization of cordierite (because of its lower crystalloblastic force). It may be that when the knotted schists were formed a certain stress environment existed which favoured the andalusite (it is realized, however, that cordierite is reported to appear abundantly in knotted schists at Albury and in Victoria) whereas cordierite came into its own in the high-grade zone where the stress influence was slight.

At this stage of the metamorphism potash felspar may appear, but examination of the role it plays is rendered difficult by the amount of alteration (mainly sericitization) which it has suffered. Commonly, however, there is no extensive development of felspar porphyroblasts as has been described in the high-grade rocks at Cooma and it is not until the granite contact is reached that relatively large felspars are seen. The potash felspar is typically untwinned and is commonly associated with grains of albite-twinned (and some untwinned) oligoclase (Ab_{85-90}). Perthitic intergrowths are a common feature and they become obvious in the porphyroblasts at the granite contact. Small felspar grains displaying myrmekite have been noted in some high-grade rocks. As both felspar and cordierite tend to be converted to micaceous aggregates it is sometimes difficult to distinguish the completely altered patches. Usually, however, the sericitic aggregates after felspar have a greyish or brownish colour and a more patchy appearance than the alteration products of cordierite, which are often yellowish, have iron oxide-stained cracks and, occasionally, haloes round small inclusions.

Both biotite and muscovite are abundant in the high-grade rocks. The biotite is normally of the red-brown, intensely pleochroic variety (Z = dark red-brown; Y = dark red-brown; X = pale straw-yellow; $Z \geqslant Y \gg X$; $\gamma = 1{\cdot}637\text{–}1{\cdot}640$) characteristically rich in inclusions with pleochroic haloes. Near the granite contacts the biotite often





Text-figure 8.—ACF diagram for the cordierite-anthophyllite subfacies of the Amphibolite Facies. Rocks with deficient K_2O and excess SiO_2. (After Eskola.)

Key: 1-4, This paper, Table 6, nos. 1-4. 5, Joplin (1947), Table 1, no. IV. 6, Joplin (1942), Table 7, no. VII. 7, This paper, Table 6, No. 5. 8, Tattam (1929), Table III, no. 22. 9, This paper, Table 6, no. 6. 10, Joplin (1942), Table 5, no. IV. 11, This paper, Table 6, no. 8. 12, This paper, Table 6, no. 9. 13, This paper, Table 2, no. 1. 14, Joplin (1942), Table 3, no. IV. 15, Joplin (1947), Table 1, no. I. Nos. 1-12 high-grade rocks; 13-15 knotted schists.

Text-figure 9.—AKF diagram for rocks with excess SiO_2 and Al_2O_3 in the staurolite-kyanite subfacies of the Amphibolite Facies. (After Turner, 1948.)

Key: 1, This paper, Table 2, no. 1. 2, Joplin (1942), Table 3, no. IV. 3, Joplin (1947), Table I, no. 1. 4, Tattam (1929), Table 1, no. 3. 5, Tattam (1929), Table 1, no. 5. 6, Tattam (1929), Table 1, no. 6. 7, This paper, Table 6, no. 1. 8, This paper, Table 6, no. 2. 9, Joplin (1942), Table 7, no. IV. 10, Joplin (1942), Table 7, no. V. 11, Joplin (1947), Table 1, no. IV. 12, Joplin (1942), Table 7, no. VII. 13, This paper, Table 6, no. 5. 14, Tattam (1929), Table 3, no. 22. 15, This paper, Table 6, no. 6. 16, Joplin (1942), Table 5, no. IV. 17, This paper, Table 6, no. 8. 18, This paper, Table 6, no. 9. 19, This paper, Table 1, no. 1.

Nos. 1-6 are knotted schist zone rocks, 7-18 are high-grade rocks, 19 belongs to the biotite zone.

seems to become unstable and breaks down to chlorite, with the TiO_2 of the mica being released as rutile forming sagenite webs. Such rutile is sometimes seen in the red-brown biotite (though more common in chlorite), apparently indicating that the TiO_2 is lost (in part at least) before the mica is changed to chlorite. Contrasted with the behaviour of the coloured mica, muscovite increases in importance near the granite and large plates of white mica are often developed enclosing pre-existing mineral grains.

Near the granite contact at the north-western end of the Green Hills mass large porphyroblasts (up to half an inch long) of sillimanite appear in the pelitic granulites. In every case the sillimanite displays extensive alteration to white mica, only small unaltered cores remaining to indicate the original nature of the porphyroblasts. Small rods and needles of the mineral occur further from the granite margin but the porphyroblastic development is quite localized. Biotite has, in some cases at least, provided the material for the formation of sillimanite (the change biotite → sillimanite is particularly obvious in the pelitic inclusions in the granite). The production of sillimanite probably represents the peak of the thermal metamorphism. As needles of sillimanite occur in the pink andalusite (Plate vi, F) in some cases it is suggested that the latter formed after the sillimanite.

The alteration of sillimanite to mica is probably due to the metasomatic addition of bases (mainly potash) and is reminiscent of the New England region studied by Billings (1938) where sillimanite-schists have been "muscovitized" by the introduction of potash. Owing to the absence of analyses of completely "unmuscovitized" high-grade rocks we cannot demonstrate the chemical changes involved as well as Billings did. Table 7 does, however, show that a high-grade rock (2) has a distinctly higher potash/alumina ratio than that of a lower-grade (biotite zone) rock (1) and that the differences are of the same order as those found by Billings (columns A, B, and C).

TABLE 6.
High-grade Metasediments.

	1	2	3	4	5	6	7	8	9
SiO_2	49·53	54·01	54·63	56·05	63·97	69·98	73·64	74·59	81·85
Al_2O_3	26·53	24·41	25·35	24·91	18·13	14·66	13·89	12·71	8·75
Fe_2O_3	2·17	1·39	2·40	1·22	1·92	1·91	0·70	0·61	0·47
FeO	6·01	5·95	4·64	4·76	4·34	4·45	4·04	4·21	2·68
MgO	3·15	2·91	2·75	2·51	2·83	2·39	1·98	0·78	0·82
CaO	0·37	0·36	0·65	0·51	0·19	0·19	0·28	0·67	0·34
Na_2O	1·23	1·09	0·62	1·06	0·92	0·50	1·12	1·31	1·19
K_2O	5·90	5·45	6·28	6·12	4·58	3·92	2·88	3·29	2·54
H_2O+	3·79	2·64	1·25	1·23	1·60	0·89	0·42	1·29	0·96
H_2O-	0·31	0·28	0·26	0·22	0·26	0·18	0·07	0·17	0·24
TiO_2	1·03	0·85	0·86	0·86	0·69	0·71	0·63	0·63	0·25
P_2O_5	—	0·15	0·20	0·14	0·27	—	—	—	0·10
MnO	0·06	0·07	0·05	0·11	0·03	0·04	0·06	0·03	0·05
Etc.	—	—	0·15	0·09	—	—	—	—	—
	100·08	99·56	100·09	99·79	99·73	99·82	99·71	100·29	100·24

1. Spotted granulite. East end of Yaven Creek bridge, Por. 51, Par. of Dutzon, Co. Wynyard. Anal. T. G. Vallance.
2. Spotted granulite. Mt. Pleasant Creek, Por. 32, Par. of Wallace, Co. Wynyard. Anal. T. G. Vallance.
3. Spotted granulite. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942 : 181.
4. Mottled gneiss. Cooma area. Anal. G. A. Joplin. *Ibid.*, p. 181.
5. Granulite. Por. 32, Par. of Wallace, Co. Wynyard. Anal. T. G. Vallance.
6. Cordierite-rich granulite. East side of Por. 35, Par. of Dutzon, Co. Wynyard. Anal. T. G. Vallance.
7. Corduroy granulite. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942 : 168.
8. Quartz-rich granulite. Por. 66, Par. of Cunningdroo, Co. Wynyard. Anal. T. G. Vallance.
9. Granitized quartz-rich granulite. Near granite margin, east side of Por. 228, Par. of Tenandra, Co. Clarendon. Anal. T. G. Vallance.

Obviously potash has been concentrated and one explanation of this increase might be by the late addition of K_2O from the granite. Billings suggested that potash is derived by the hydrolysis of potash felspar in the plutonic rocks:

$$\underset{\text{orthoclase}}{6KAlSi_3O_8} + 2H_2O \rightarrow \underset{\text{muscovite}}{2H_2KAl_3Si_3O_{12}} + 2K_2O + 12SiO_2$$

Muscovite does occur in the granites but it would be a matter of difficulty to prove whether it is wholly or partly related to the release of potash to the nearby metasediments. The late glassy-quartz veins which cut the high-grade rocks in a few places may represent the destination of some of the silica freed by such a process as that postulated by Billings.

Holmes and Reynolds (1947) have suggested a similarity between Billings' New Hampshire occurrence of "muscovitization" of high-grade rocks and certain Dalradian rocks in Donegal in which quartzite is converted to mica schist. They disagree with Billings' explanation and state that "the migrations involved in the metasomatic metamorphism of the Malin Head Quartzite (and presumably that of the Loon

Mountain schists [Billings]) . . . were of the far-travelling type characteristic of migmatite fields and the surrounding zones of regional metamorphism".

In the present case the late muscovite-enrichment in the high-grade rocks is greatest around the margins of the plutonic masses and mainly occurs in proximity to them. The evidence we have concerning the alteration of the various minerals (sillimanite, cordierite, and felspar) leads to some interesting time relations. The porphyroblasts of the knotted schists must have been altered before the end of the metamorphism because of the variation in the mineralogy of the aggregates which replace them (brown biotite develops in the higher-grade knots whereas nearer the outer limit of the knotted schist zone fine sericite is characteristic). Permeation by alkali-bearing solutions must at some stage have extended out as far as the knotted schist zone. One would naturally expect that these solutions would have been most active in the deeper high-grade zone and the fact that cordierite porphyroblasts, for example, are only partly altered in the high-grade rocks (cf. knotted schists) suggests

TABLE 7.

Examples of Potash-enrichment in High-grade Rocks.

	1	2	A	B	C
$\frac{K_2O}{Al_2O_3}$	0·18	0·27	0·19	0·17	0·31
$\frac{Na_2O}{Al_2O_3}$	0·05	0·03	0·09	0·07	0·04
$\frac{K_2O+Na_3O}{Al_2O_3}$ ..	0·23	0·27	0·28	0·24	0·36

1. Fine-grained psammopelite (Biotite Zone). This paper, Table 1, No. 1.
2. Cordierite-rich granulite. The cordierite is now extensively altered to mica. High-grade Zone. This paper, Table 1, No. 2.

A. Slate. Low-grade Zone.
B. Sillimanite Schist. High-grade Zone.
C. Muscovitized Schist. High-grade Zone.

Note.—A, B, and C belong to the Littleton Formation (New Hampshire) and are quoted from Billings (1938), Table 4.

that they did not suffer this action. Development of brown biotite in the aggregates of the higher-grade rocks is perhaps correlable with the trend towards the sillimanite peak of metamorphism and following this may have come a final "muscovitization". The sillimanite, cordierite and pink andalusite may thus belong to a rather later generation than the porphyroblasts of the knotted schists. Of the two "muscovitizations" only the later one may have been directly related to the presence of the granite.

Discrete veins and tongues of leucocratic quartzo-felspathic material occur in the high-grade zone in close proximity to the margin of the Green Hills granite (and to a smaller extent near the Wantabadgery granite). These mixed rocks (migmatites or injection rocks) are similar in many respects to the more extensive injection rocks found at Cooma. In the case of the pelites the metasedimentary host material may be mottled or spotted and granular like the granulites mentioned above. At times the host material becomes coarsely crystalline and there may be a concentration of biotite (a biotite selvedge) in the host near the vein margin. The vein material may carry subordinate muscovite and red-brown biotite in addition to the abundant quartz and felspar. Brown tourmaline may also occur in the veins.

It has been seen that the pelites in the high-grade zone tend, in general, to assume the appearance of spotted granulites but the transition to such rocks from the knotted schist stage is rather gradual. This transition suggests a possible development-stage in the history of these rocks which was not recorded at Cooma (Joplin, 1942). There the "spots" were regarded as pelitic fragments which had been disrupted by the formation of orthoclase porphyroblasts. In the present case the spots seem to represent altered porphyroblasts of andalusite and/or cordierite comparable with those that form the knots in the knotted schists. The micaceous spots occur in the granulites even where orthoclase is of minor importance and certainly could have had no extensive mechanical action. The best explanation seems to be that the spots of the granulites (in the outermost parts of the zone at least) are actually highly recrystallized mica-aggregates corresponding to the altered knots of the schists. It is interesting to note that green biotite may occur in the spots of the granulites whereas only the typical red-brown variety is developed in the base of such rocks. Comparison of analyses of pelites and of altered "nodules" from a Victorian knotted schist (see Tattam, 1929, Table I, no. 6; these are the only altered porphyroblasts from knotted schists in this metamorphic belt which have been analysed) will indicate a fairly close correspondence (except for magnesia and to some extent iron). Conceivably both pelite fragments and mica-replaced porphyroblasts could provide the material for the spots in the granulites in different cases. In the higher-grade parts of this zone the dark micaceous spots of the granulites are separated by felspar-rich leucocratic veins or patches and it may be that there the development of felspar has helped to break down the original pelite material. It seems not unreasonable to regard the early-stage spotted granulites as derived from knotted schists by recrystallization whereas with the development of more felspar (perhaps by addition due to metasomatism) internal disruption may accentuate the spotting of the granulites.

A summary of the probable history of these rocks might be: (1) production of knotted schists under (mainly) thermal influence, followed by (2) alkali metasomatism causing alteration of the porphyroblasts to mica aggregates, (3) increase in thermal intensity resulting in the recrystallization of the mica aggregates (with the development of biotite, etc.) and the granulitic appearance of the rocks with the micaceous patches remaining as relics. The generation of sillimanite, cordierite, potash felspar, and perhaps pink andalusite belongs to this period. Finally with waning temperature (4) potash-rich solutions caused the breakdown of the high-grade aluminous minerals (except andalusite) to muscovite. The high-grade environment may have been, in part, superimposed on the knotted schists as the metamorphism progressed to its peak (3). Such observations indicate that the metamorphism although in a general sense progressive must have taken place in a number of stages, just as was decided after examining the knotted schists.

(ii) *Psammopelites and Psammites.*

The general trend of mineral transformations in the pelitic rocks is also shown by the sandier types, though the metamorphic representatives of the latter in this zone are more quartz-rich and often more granular than the isogradal pelites. As a rule the banded psammopelites preserve their original sedimentary banding till a more advanced stage than the other metasediments. The mottled or spotted pelitic bands in these rocks behave exactly as do the normal pelites whilst the sandier bands are recrystallized to granoblastic aggregates of quartz, red-brown biotite, muscovite, and sometimes felspar. In appearance such banded rocks are similar to the corduroy granulites described from Cooma (Browne, 1914; Joplin, 1942).

Towards the granite contact it becomes apparent that the sandy rocks have been more easily permeated than the accompanying pelites. The increase in size of the K-felspar grains with approach to the granite suggests that part, at least, of the necessary material for their formation has come from the granite by some process such as metasomatism. The felspar porphyroblasts near the contact may grow to about half to one inch long and are commonly marked by fine perthitic intergrowths. Oligoclase is a frequent associate of the K-felspar and it exhibits a greater proportion of twinned grains near the granite than away from it. Where the bulk composition permits, cordierite, always more or less altered, may occur as rather regular idioblasts. Andalusite does not usually appear in these more homogeneous rocks but it does occur in the pelitic bands of the corduroy granulites. Regarding the development of cordierite rather than andalusite in this case, there may be some significance in the fact that the psammopelites when plotted on an ACF diagram (Text-fig. 8—points 8–12 represent psammopelites, the remainder are pelites) tend to fall farther away from the A (andalusite) pole and nearer the F pole than the normal pelites; the separation is, however, never very great.

As in the case of the pelites the sandy rocks near the granite may display the features of banded migmatites or injection rocks. The vein material is in general comparable with the leucocratic quartzo-felspathic material mentioned in connection with the pelites. Banded gneisses of mixed origin may thus occur locally along the edge of the Green Hills granite mass. Veins of coarse glassy quartz (later than the quartzo-felspathic veins) occur in such rocks near Hugel Trig. Station.

(iii) *Tourmalinization of High-grade Metasediments.*

Metasediments rich in tourmaline are scattered at intervals along the granite contacts and have been studied near Alfred Town, north of Bilda Trig. Station, and near the north-west end of the Green Hills mass. Tourmaline as an accessory is widespread in all the metasediments of this region and though variable in colour is most commonly of the blue-grey pleochroic type. The boron-rich rocks on the other hand are quite exceptional and are characterized by pleochroic brown tourmaline. These rocks occur only in close proximity to dykes and veins of the acid phases (aplites or pegmatites) of the granite.

All gradations may be seen from the extreme case of pure quartz-tourmaline rocks to little-affected types with only a few brown tourmaline grains associated with the usual minerals of the metasediments. The process of tourmalinization appears to involve the replacement of all the components of the metasediments (except quartz) by tourmaline. Biotite is usually the first mineral to disappear, followed by felspar and then muscovite. The replacing tourmaline is a strongly pleochroic (E = pale fawn; O = very dark brown) variety of schorlite occurring as ragged crystals, often rich in quartz inclusions. In the completely replaced rocks (i.e. the quartz-tourmaline rocks) there is often a marked dimensional orientation of the tourmaline grains. Late crystallization of quartz in veins is not an unusual feature of these rocks.

The field relations strongly suggest that these tourmaline-rich rocks are due to the addition of boron from the plutonic rocks. Tourmaline occurs in many of the pegmatites and aplites, though it is in general rather rare in the normal granites and granodiorites. It seems reasonable to regard the association of tourmaline-rich rocks with acid phases of the granite as being of genetic significance. The phenomenon of boron metasomatism is by no means rare and has been often invoked to explain the extensive development of tourmaline-rich rocks in proximity to plutonic masses (Turner, 1948, p. 127). As Turner pointed out, the process leads to a mineralogical convergence whereby a pelite, for example, of rather complex mineralogy is reduced to a quartz-tourmaline mixture. It is of interest to note here that Howitt, in 1888, described certain tourmaline-bearing rocks from Omeo, Victoria, in the same metamorphic belt as the present area; he ascribed the tourmaline to "volatile emanations" from plutonic magmas.

The evidence available in this area points to a rather restricted extent for the boron metasomatism. In every case where tourmaline becomes important it is near acid phases of the granite, whilst the accessory tourmaline (usually of different colour) of wide distribution in the metasediments may be quite reasonably regarded as being of detrital origin. Contrary to the opinions of some petrologists (see Hutton, 1939), the boron has apparently not travelled far from its source, certainly not as far as the alkali-rich solutions which caused the rather extensive production of late sericite or muscovite in the alumina-rich rocks.

Review of the Metamorphism in the Light of the Facies Concept.

Now that some picture of the metamorphic progression and of the rocks formed in the various stages has been given it will be useful to attempt briefly to relate the results to the appropriate metamorphic facies (see Turner, 1948).

The metasediments which we have considered belong, for the most part, to a group of rocks with excess silica and alumina and deficient potash (relative to alumina).

The remarkable uniformity in composition has been reflected in the rather constant mineral assemblages found in the rocks in a given metamorphic grade.

The low-grade rocks with the definitive association sericite (muscovite) and chlorite belong to the muscovite-chlorite subfacies of the Greenschist Facies (see Turner, 1948, p. 96). The antigorite-rich assemblage of the silicified serpentine also belongs here. With the development of brown biotite (characteristic of the biotite zone) the grade of metamorphism becomes equivalent to the biotite-chlorite subfacies of the same facies as the low-grade rocks.

Andalusite and/or cordierite associated with albitic felspar in the outer part (at least) of the knotted schist zone bespeaks a grade of metamorphism corresponding to the actinolite-epidote hornfels subfacies of the Albite–Epidote–Amphibolite Facies (Turner, 1948). When more calcic plagioclase (in this case oligoclase) is developed along with the andalusite and/or cordierite in the pelitic schists Amphibolite Facies conditions are indicated. Such conditions probably applied in the more metamorphosed part of the knotted schist zone and certainly applied over a large portion of the high-grade zone. The mineral assemblages suggest that a cordierite-anthophyllite subfacies environment prevailed here. Text-figure 8 shows the positions of various high-grade rocks on an ACF diagram as devised for this subfacies. It can be readily seen that these rocks might be expected to give such mineral assemblages as (*a*) muscovite-andalusite-cordierite-plagioclase-(quartz), (*b*) muscovite-biotite-cordierite-plagioclase-(quartz) (see Turner, 1948, p. 79). Such associations do occur here but, as the diagram suggests, plagioclase is subordinate. Potash felspar is unstable in this subfacies in association with andalusite or cordierite. It has been noted, however, that potash felspar does appear in some of the high-grade rocks and it becomes commoner as the granite contacts are approached. Sillimanite also occurs under these conditions. The assemblages in which such minerals occur are not in complete equilibrium but they do suggest a change from the cordierite-anthophyllite subfacies. The association potash felspar-sillimanite is a possible one in the sillimanite-almandine subfacies of the Amphibolite Facies, and it may also occur in the Pyroxene Hornfels Facies. Besides certain of the high-grade rocks of the country-rock metasediments this association may also appear in the pelitic inclusions in the Wantabadgery and Green Hills granites. If these high-grade types belonged to the sillimanite-almandine subfacies, then, if equilibrium were attained, almandine garnet should appear in rocks of this composition. Although ideal equilibrium conditions have not been realized there should be some tendency for garnet to appear if such an environment once prevailed here; almandine has not been recorded from these rocks. On the other hand there is equally no tendency for pyroxene to appear in any of the metasediments. No basic rocks which might develop pyroxene under Pyroxene Hornfels Facies conditions occur in close proximity to the high-grade zone. Pyroxene has been noted (associated with amphibole) in a large inclusion in the Wantabadgery granite at Mundarlo; it has also been seen in certain basic rocks from the "basic belt" between Adelong and Batlow. Discussion of the significance of pyroxene in the latter rocks must be deferred, but it may be noted that the mineral tends to develop in some of these rocks as they are followed southwards along the strike, suggesting a possible metamorphic relation to the Green Hills granite and the general metamorphism rather than to the Ellerslie-Wondalga granite with which the pyroxenic rocks may come in contact. Hornblende-pyroxene granulites also occur as xenoliths in the Cooma gneiss (Joplin, 1942, p. 171) which bears much the same metamorphic relations to the metasediments at Cooma as does the Green Hills granite to the metasediments here. All this suggests to me a transition from Amphibolite to Pyroxene Hornfels Facies and it is believed that the high-grade metasediments reflect the same tendency.

The introduction of potash and the production of mica in the higher-grade rocks have thrown all the mineral assemblages into disequilibrium. In developing this broad facies picture I have attempted to restore the mineralogy of the various metasediments to what it probably was before these disturbing influences caused the retrogression.

It is felt that despite this present disequilibrium the metamorphic facies progression is sufficiently clear to merit our attention.

In the Cooma study Dr. Joplin correlated her metamorphic zones with those devised by Barrow (see p. 98) for the Dalradian of Scotland and believed that Barrow's almandine, staurolite and kyanite zones were missing. She related the high-grade rocks (permeation and injection zones) to Barrow's sillimanite zone and referred to a "metamorphic unconformity" existing between the biotite and sillimanite zones. Actually there seems to be no need for postulating such a break and from a consideration of the various facies there is not much evidence for it. There was probably a waxing and waning of the temperature/stress ratio and various other complicatory events such as alkali-metasomatism during the metamorphic history of this area but, broadly speaking, the facies involved belong to a series indicating a general increase in grade with approach to the granite masses. Table 8 shows the suggested sequence of

TABLE 8.

Metamorphic Zones and the Equivalent Facies and Subfacies (partly after Turner, 1948).

	Barrow's Zones.	Facies and Subfacies.		Zones Used in this Study.
Increasing Temperature ↓		GREENSCHIST FACIES		
	Chlorite Zone	Muscovite-chlorite subfacies	Muscovite-chlorite subfacies	Low-grade Zone
	Biotite Zone	Biotite-chlorite subfacies	Biotite-chlorite subfacies	Biotite Zone
		——*Temperature/Stress Increasing*——→		
		ALBITE-EPIDOTE AMPHIBOLITE FACIES		
	Garnet Zone (Almandine)	Chloritoid-almandine subfacies	Actinolite-epidote hornfels subfacies	
				Knotted schist Zone
		AMPHIBOLITE FACIES		
	Staurolite Zone	Staurolite-kyanite subfacies		
	Kyanite Zone			
			Cordierite-anthophyllite subfacies	High-grade Zone
	Sillimanite Zone	Sillimanite-almandine subfacies		
		PYROXENE HORNFELS FACIES		

facies and subfacies encountered in this study (they also occur at Cooma) and the zonal correlation together with Barrow's zonal series and the appropriate facies and subfacies (mainly after Turner, 1948). In both cases the same facies are involved but, except in connection with the Greenschist Facies, rocks from the two areas (the Grampian Highlands of Scotland and the present area) belong to different subfacies. Barrow's subfacies equivalents are indicative of a more dynamothermal metamorphism than those referred to in this paper which bespeak a more thermal type (with less stress influence relative to the thermal effect) of metamorphism. This significant difference was noted by Joplin (1942). Fig. 9 (see p. 113) indicates that under the appropriate physical conditions the metasediments here described would have developed Barrow's index mineral staurolite (almandine might have been formed at a lower-grade stage) instead of the andalusite and cordierite. I do not believe that the high-grade zones at Cooma and in the Wantabadgery-Adelong-Tumbarumba area are strictly correlable with Barrow's sillimanite zone (Joplin, 1942, p. 194) which, according to Turner, represents the sillimanite-almandine subfacies of the Amphibolite Facies, but rather that the development of sillimanite represents an incomplete transition to a higher-grade facies. Turner (1948) quotes the work of Tattam (1929) in the north-eastern Victorian complex in connection with the mineral reaction biotite → sillimanite shown by some of the rocks of that area; a similar transition occurs in this area, especially in the pelitic inclusions in the granites but also to some extent in the country-rocks. Turner suggests that the reaction is typical of the sillimanite-almandine subfacies, but it seems probable that it is not confined to that particular environment.

The foregoing remarks serve to show that the metamorphic progression described in this paper runs, in a sense, parallel to the Dalradian metamorphic sequence of George Barrow; they also emphasize the fact that Barrow's zones represent but one type of metamorphic progression. In the present case the metamorphism was regional in extent but had an important thermal factor. Consideration of the problem of the relation between the granite masses and the metamorphism must be deferred until the granites themselves have been described.

EXPLANATION OF PLATES V AND VI.

Plate v.

Geological sketch map of the Wantabadgery-Adelong-Tumbarumba district.

Plate vi.

A. Banded low-grade siliceous metasediment from the western side of the jasper belt near Nangus. Note the contortions and rupture induced by the deformation after the development of the schistosity. Granular quartz has been deposited along the lines of fracture. Ordinary light.

B. Siliceous serpentine-bearing rock. Patches of fairly coarse fibrous antigorite occur in a matrix of finer antigorite, talc, chalcedony, and calcite. Note the chalcedony vein (dark) with faint marginal radiating growths. Crossed nicols.

C. A rather coarse sandy psammopelite (subgreywacke) from the knotted schist zone. There is a general orientation of the sand grains (quartz, felspar, and a few rock fragments) in a matrix now consisting of biotite and muscovite. Some of the sand grains show signs of granulation. It is clear that this rock has retained more detrital features than has the isogradal finer-grained type (no. D). Crossed nicols.

D. Psammopelite from the knotted schist zone. Mica flakes are distinctly recrystallized and show a preferred orientation along the obvious schistosity. Ordinary light.

E. Knotted schist (pelite) from near the high-grade zone outer limit. The photograph shows a lustrous schistosity-plane with large euhedral micaceous pseudomorphs after andalusite (?—most crystals are defaced but andalusite forms (001), (011), and (110) are visible in some cases). The scale is in inches.

F. Spotted granulite (pelite) from the high-grade zone. Note the fresh andalusite porphyroblast (right of centre) with a granular marginal zone; the irregular patch in the core is an aggregate of sillimanite needles. To the left of the big andalusite grain is a ragged porphyroblast of cordierite now completely replaced by a fine mica aggregate. The rock is distinctly more granular than the lower-grade schists. Ordinary light.

Magnification of nos. A, B, C, D, and F is $\times 13$.

Photographs by G. E. McInnes.

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CYTOLOGY OF *SEPTORIA* AND *SELENOPHOMA* SPORES.

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(Plate vii; three Text-figures.)

[Read 29th July, 1953.]

Synopsis.

The Giemsa stain was used to demonstrate the nuclear condition in macrospores of species of *Septoria* and *Selenophoma,* and in species of *Ascochyta, Colletotrichum, Fusarium, Gloeosporium, Neurospora* and *Phyllosticta.* One nucleus per cell was recorded for all species except *Neurospora.* The nuclei in the immature, one-celled spores of *Septoria nodorum* consisted of 5-7 fragments. One nucleus, linear in form, was demonstrated in the micropycnidiospores of *Septoria tritici.* The nuclei in the germ tubes and hyphae of some of the species were also studied, and in many cases were found to be elongated. The small nuclei in hyphae and conidia of *Neurospora tetrasperma* were rounded.

Several other methods, involving different fixatives and stains, were used, and the results obtained with Giemsa were confirmed. No nuclei could be detected in living spores of *Septoria* and *Selenophoma* species with the phase contrast microscope.

Spores of species of *Septoria*, *Selenophoma* and *Ascochyta* from the field and from culture were stained to demonstrate the amount of fat present and its distribution in the spores.

1. The Nuclear Condition.

The nuclear condition of species of *Septoria* and *Selenophoma* (particularly of those occurring on Gramineae in Australia) was investigated.

There is very little information in the literature concerning the nuclear condition of either the spores or the mycelium of these genera. Sprague (1934), when describing the spores of *Septoria tritici* f. *avenae*, stated "the contents are homogeneous, with nuclei and nucleoli clearly evident". Moore (1940) cited the description of Ellis and Martin of *S. consimilis* on lettuce (held to be similar to *S. lactucae*) as "spores filiform, multinucleate". In their detailed study of the structure and germination of *Septoria* spores, McMillan and Plunkett (1942) noted, however, that "in no protoplast, stained or unstained, has there been any structure that could be construed as a nucleus". MacNeill (1950) published a preliminary note on a study of *S. lycopersici,* stating that "the Feulgen stain, modified to suit the type of material at hand, indicates a uninucleate condition of both spore and mycelial cells". Shaw (1951) found that nuclei were clearly visible in spores and sporophores of *S. pepli* in sectioned diseased leaves stained with gentian violet-orange G. In this case, however, the septations were not clear, so that the number of nuclei per cell could not be determined.

The nuclear condition of the micropycnidiospores in some species of *Septoria* has not previously been determined.

There appear to be only two references to the nuclear condition of species of *Selenophoma.* Allison (1945) reported that the spores of *S. bromigena* were slightly guttulate, non-septate and multinucleate. Vanterpool (1947) recorded that the spores of *S. linicola* on flax may be either uninucleate or multinucleate.

Methods.

A method was sought whereby spores and mycelium could be stained without embedding and sectioning. The aceto-orcein and aceto-carmine methods of McClintock (1945) and the aceto-carmine method of Cherewick (1944) were not successful. The Method 2 of Robinow (1944), of dipping unfixed, air-dried impression preparations for five seconds into boiling N/5 HCl, rinsing and mounting in 0·1% crystal violet in water, was also unsuccessful.

The following methods were found to give good results with the organisms tested. In all cases spores were allowed to exude from pycnidia into a drop of tap water on grease-free slides, or secondary conidia or mycelium were added to the water, direct from cultures. In most tests the water was allowed to evaporate at room temperature. When germinating spores were required, the slides were placed in petri dishes with moist cotton wool, taken out after the required length of time, and allowed to air-dry. The spores or mycelium adhered to the slides throughout all the subsequent treatments.

Method 1.

This method is a modification of one used by Knaysi, Hillier and Fabricant (1950), whose technique has been used successfully with bacteria by Mr. A. D. Rovira, of the Microbiology Department, Faculty of Agriculture, University of Sydney. The method as adapted for the fungal material is as follows: (i) fix air-dried spores in 95% alcohol for 12–15 minutes; (ii) hydrolyse in N HCl at 60°C. for 6–15 minutes; (iii) wash in tap water for one minute; (iv) stain with 10% Giemsa for approximately one hour; (v) wash in tap water for one minute, and either allow to dry and examine under oil immersion or dehydrate in the acetone/xylol mixtures of Robinow (1944), mount in euparal and examine under oil: or allow to dry, mount in euparal and examine under oil.

This method is quick and has given consistently good results. The nuclei stain vivid red-purple, and the cytoplasm stains very faint mauve.

Air-drying alone has been used for fixation, e.g., for the study of mitoses in peripheral embryonic blood and for yeast cells, followed by hardening in 95% alcohol (Darlington and La Cour, 1947, p. 67 and p. 61 respectively). Knaysi *et al.* (1950) considered that fixation with alcohol dissolved lipids and so increased the penetration of the dye into the cellular structures of *Mycobacterium tuberculosis.*

Air-drying was done at room temperature, or at higher temperatures over a microscope lamp. Alcohol was added to the slides while a thin film of moisture remained around the spores, and was then allowed to evaporate. There appeared to be no difference in the results.

The time of fixation by 95% alcohol was varied from 1 to 15 minutes without appreciably altering the results. The time of hydrolysis varied from 1 to 15 minutes: best results were obtained with hydrolysis of 6–15 minutes, depending on the species. Best results were obtained when tap water (pH just over 7) rather than distilled water was used for washing.

Shaw (1952) used the above method to show the nuclear condition of sporidia of *Tolyposporium restifaciens*, and it has been the main method used throughout this study. Barratt and Garnjobst (1949) also used an acid Giemsa stain to determine the number of nuclei in macro- and microspores of *Neurospora crassa.*

The other methods were used to determine whether the same picture of the nuclear condition was obtained (*a*) by using a different fixative and (*b*) by using another stain. No major differences were detected in the nuclear condition with the other methods.

Method 2.

(i) Treat the air-dried spores according to Robinow (1944) by fixing in the vapour of 5 ml. of 2% osmium tetroxide for three minutes and allow to dry; (ii) immerse in 70% alcohol for five minutes; (iii) hydrolyse in N HCl at 60°C. for ten minutes; (iv) stain with 10% Giemsa for one hour; (v) subsequent treatment as Method 1.

The nuclei stain red and the cytoplasm stains faintly mauve.

Method 3.

(i) Immerse the air-dried spores in water at 80°C. for 10–20 minutes. This procedure was used by Knaysi *et al.* (1950) in tests with desoxyribonuclease on *M. tuberculosis*; (ii) wash several times in water; (iii) stain with 10% Giemsa for one hour; (iv) subsequent treatment as Method 1.

The result obtained is not as clear as with Method 1, but proved particularly good for spores of *Selenophoma donacis* produced in culture. The nuclei stain red and the cytoplasm mauve.

Method 4.

As a further check on the nuclear picture, spores were stained by the Feulgen technique. The leuco-basic fuchsin was prepared according to the modified formula after de Tomasi (1936) and Coleman (1938), as given by Darlington and La Cour (1947). Subsequent treatment was mainly as recommended by the Botany Department, University of Sydney: (i) Fix in acetic alcohol (3:1) for ten minutes; (ii) take through the alcohols from absolute to water; (iii) hydrolyse in N HCl at 60°C. for six minutes; (iv) stain in leuco-basic fuchsin for 15–24 hours; (v) wash in sulphite water four times (ten minutes each); (vi) rinse in distilled water; (vii) take through 20%, 60%, 80% and absolute alcohol; (viii) mount in euparal.

This method is longer than the preceding ones, and great care has to be taken in preparing the leuco-basic fuchsin. The nuclei stain reddish-purple and the cytoplasm faint pink.

Method 5.

For an approximate picture of the nuclear condition, very dilute cotton-blue lactophenol can be used. The nuclei stain deep blue, the cytoplasm blue, and the guttulae remain unstained.

Live spores of species of *Selenophoma* and *Septoria* were also examined under the phase contrast microscope, both in phase and with dark field, but no nuclei could be detected.

Examination of stained material was made with a Zeiss microscope using a combination of 90X apochromatic objective (N.A. = 1·3) and 20X and 15X oculars. Photographs were taken using the same microscope and objective, and a 12X ocular with trichrome green filter and Process Pan film. A few photographs were taken by Mr. Woodward-Smith and these are so specified.

RESULTS.

Examination was made of spores of the following species of *Septoria* and *Selenophoma*, from the field (F) and from culture (C). Spores of species of *Ascochyta*, *Colletotrichum*, *Fusarium*, *Neurospora* and *Phyllosticta* were also included in the tests. Germinating spores and mycelium were studied in the species marked †.

Fungus.	Host.	Source.
Septoria avenae.	*Avena sterilis.*	F†
S. avenae f. *triticea.*	*Triticum vulgare.*	F†
S. bromi.	*Bromus molliformis.*	F & C
S. macropoda.	*Poa annua.*	F
S. nodorum.	*Triticum vulgare.*	F†
S. tritici (macro- and micro-pycnidiospores).	*T. vulgare.*	F & C†
S. tritici var. *lolicola.*	*Lolium multiflorum.*	F & C†
Septoria sp.	*Anthoxanthum odoratum.*	F
S. apii-graveolentis.	*Apium graveolens.*	F
S. dianthi.	*Dianthus barbatus.*	F
S. dianthi.	*D. caryophyllus.*	F
S. lactucae.	*Lactuca sativa.*	F
S. lactucae.	*L. scariola.*	F
S. lycopersici.	*Lycopersicon esculentum.*	F
S. pepli.	*Euphorbia peplus.*	F
Septoria sp.	*Erodium cygnorum.*	F
Septoria sp.	*Silene gallica*	F
Septoria sp.	*Stellaria media.*	F
Selenophoma donacis.	*Arundo donax* (?).	F & C†
S. donacis var. *stomaticola.*	*Agropyron scabrum.*	F & C†
S. donacis var. *stomaticola.*	*Triticum vulgare.*	F & C†
Ascochyta sp.	*Bromus unioloides.*	F†
Colletotrichum graminicolum.	*B. unioloides.*	F
Fusarium sp. (macro- and micro-spores).		C
Gloeosporium sp.		C
Neurospora tetrasperma.		C
Phyllosticta sp.	*Dichelachne sciurea.*	F

All the species of *Septoria* examined had one nucleus per cell, so that the number of nuclei per spore equalled the number of cells per spore (Plate vii, 1 and 4).

The scolecosporous or filiform-spored species of *Septoria* are generally recognized as typical of the genus. These species usually produce slow-growing yeasty colonies on P.D.A., with or without the production of secondary conidia, the cultures later becoming carbonaceous. The nuclei did not stain as easily or as vividly as the nuclei of that other type still designated by many workers as belonging to the genus *Septoria*, and typified by *S. avenae* and *S. nodorum*. This latter type has cylindrical spores which produce quickly-growing cottony cultures on P.D.A. The nuclei of the spores stained easily and vividly, and in conformity with the wider spore the nuclei were wider than the nuclei in the filiform spores.

In many preparations, under the most critical illumination, the nuclei of mature spores of *S. nodorum* could be resolved into 5–7 fairly circular fragments arranged in a circle. In immature one-celled spores pressed out of pycnidia these rounded fragments were distributed over a larger but still circular area in the centre of the spore, as in Text-figure 3. It is to be noted that in these one-celled spores there is only one area containing the nuclear fragments, so that the four nuclei in mature spores are probably all derived from a single nucleus.

The nuclear condition of micropycnidiospores of species of *Septoria* has not previously been determined. Microspores of *S. tritici* were stained by Method 1, preparations being chosen for study where macropycnidiospores were also present for comparison. One nuclear region occurred per microspore and was linear in shape, conforming to the morphology of the spore, measuring 4–5μ long $\times$ 0·8μ wide, the spores themselves being usually 8–10μ long $\times$ 0·8μ wide. The nuclear region was not homogeneous, as about five deeply-staining areas occurred close together in sequence (Plate vii, 3; Text-fig. 2).

In most cases the nuclei of spores allowed to remain in water for several hours lost some of their vividness as compared with the nuclei of freshly-exuded spores. In spores where germination had commenced from only one or two cells, the nuclei in these cells appeared more diffuse and less deeply stained than in the cells without germ tubes. In preparations showing spores after five hours in water, where more than 90% of the spores had germinated, the ungerminated spores were outstanding because of the vividness of the nuclei. In some germinating cells, however, the nuclei still stained sharply.

Nuclei appeared in the germ tubes after approximately four hours (Plate vii, 5). At that time germ tubes of *S. nodorum* and *S. avenae* were about 30μ long, and there was usually one arising from each end of the spore. The nuclei in the germ tubes in preparations obtained by the methods outlined were always longer than wide, and parallel to the direction of the hyphae. The only more or less circular nucleus detected in preparations of young germinating material was at the junction of two branches. In spores after 5–6 hours in water, two regions of chromatinic reaction, or two linear nuclei, were detected in the germ tubes. Under critical illumination many of these linear nuclei could be resolved into rounded fragments, usually about 5–7 in number, but sometimes more. In older material the nuclei were spaced rather regularly along the hyphae, and all had the linear form.

Spores were allowed to remain in water for 24 hours, by which time a weft of hyphae had been produced on the slide. This was allowed to air-dry and was treated as were the spores. The chromatinic areas were easily detected in the hyphae, were rather regularly spaced, and again had the linear form. Mycelium from one-week-old cultures of the cottony *Septoria* species (*S. nodorum*, *S. avenae*, and *S. avenae* f. *triticea*) was teased out in water on slides and treated as in Method 1. Linear nuclei were again observed, with others slightly more rounded in outline (Plate vii, 6).